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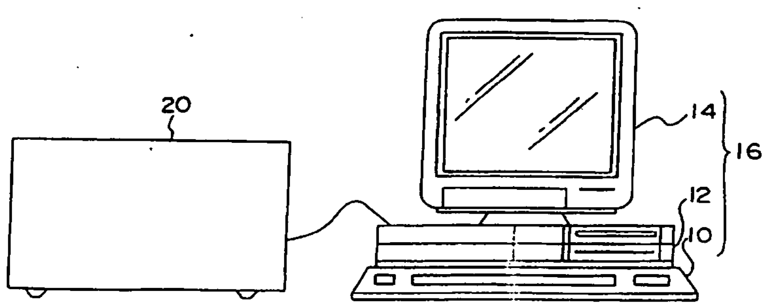
(54) **Method of selecting a coating color**

(57) Relationships of correspondence between data on a multiplicity of kinds of color and data on tristimulus values are determined in advance, and correspondence between interpolating points between inputted color data and data on the tristimulus values corresponding to the interpolation points is determined by interpolation on the basis of the determined relationships of correspondence. When a desired color is to be reproduced and outputted, tristimulus values which are identical to or closest to the tristimulus values, i.e., output values corresponding to that desired color, are selected, and color data corresponding to the selected tristimulus values is determined to reproduce the color.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to a method of selecting a coating color. More particularly, the present invention concerns a method of selecting a coating color so as to reproduce a coating color of a coated surface intended by a designer or the like when obtaining a coated surface by coating the surface with a paint or the like or when displaying a coated surface on a color CRT.

Description of the Related Art:

An object surface, such as the body of a vehicle, is formed by a coated surface having a coating color obtained by applying a paint or the like. To obtain a coated surface of a desired coating color intended by a user, a designer, and the like, a paint or the like obtained by mixing a plurality of pigments and the like by using a color sample as a reference is applied to the object.

A method is conventionally known in which, with respect to an object surface having uniform optical properties, the color of the object is reproduced and displayed three-dimensionally and realistically with accuracy with the semblance of the actual object by computing coloring on the basis of a ray tracing method using the reflectance of the object surface, such as the spectral reflectance factor (A. Takagi et al."Computer Graphics," Vol. 24, No. 4, 1990, and the like). In this method, color specification values (tristimulus values) of the CIE standard XYZ colorimetric system are first determined on the basis of a spectral reflectance factor and the like of the object surface. These tristimulus values are then converted to color specification values peculiar to the colorimetric system through a linear combination transformation, are subjected to γ correction, and are converted to RGB gradients, thereby reproducing the object color and displaying an image. According to this method, if the reflectance of the object can be specified, it is possible to reproduce and display the object color. At the same time, the reflectance of the object corresponding to the displayed color can be specified by processing in the reverse order, and virtual color components for obtaining the displayed color can be determined. It is possible to obtain a desired coating color, if the object is coated with a paint or the like obtained by mixing a plurality of pigments and the like in quantities corresponding to the quantities of these color components.

However, the setting of a ratio of mixing or compounding pigments for obtaining the desired coating color requires the trained skill of a technician, and is very low in productivity. In addition, it does not necessarily follow that the coating color on the finished coated surface can always be reproduced to the coating color intended by the user, the designer, and the like owing to differences and variations in the type of component materials such as pigments.

To overcome this problem, computer color matching (hereafter referred to as CCM) has been widely used in which compounding involving the setting of a mixing ratio of pigments, which requires trained skill, is determined by computation by a computer in compounding basic color materials (coloring agents such as pigments) in accordance with the Kubelka-Munk's theory. In this CCM, the mixing ratio and the like of a plurality of pigments whose reflectances are known are determined by computation by a computer, such that the reflectance will be equal to the reflectance of a color sample measured by a spectrophotometer or the like. In another case, the mixing ratio and the like of a plurality of pigments whose tristimulus values are known are determined by computation by a computer, such that the tristimulus values will be equal to the tristimulus values of the color sample. Thus, a method is known for determining the mixing ratio and the like of coloring agents by using CCM so as to reproduce an intended coating color (Japanese Patent Application Laid-Open No. 149760/1987).

With the conventional methods of reproducing a coating color using CCM, however, since compounding is determined in accordance with the Kubelka-Munk's theory, it is impossible to effect compounding by mixing substances whose surface reflectances do not conform to the Kubelka-Munk's theory. In addition, it is impossible to specify a coating color which includes bright materials such a metallic paint and mica as its component materials.

In addition, although the above-described CCM is effective in obtaining a coating color which coincides with a color sample or the like, reflectance values and tristimulus values for specifying the coating color are not subjective. Therefore, it is difficult for the above-described CCM to reflect trends of sensuous coating colors, such as reddish and glossy colors, which are used by designers and the like as specification for obtaining desired coating colors from already existing coating colors.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a method of selecting a coating color which makes it possible to select an optimum coating color intended by a user or a designer.

In addition, in accordance with a first aspect of the present invention, there is provided a method of reproducing a coating color, comprising the steps of: with respect to a predetermined coating color on a coated surface which is formed with one or a plurality of layers on an object to be coated and in which each of the layers is formed of at least one component material, determining in advance a plurality of relationships of corespondence between characteristic values constituted by amounts of respective ones of all the component materials constituting the coated surface and a spectral reflectance distribution of the coated surface based on the characteristic values; estimating on the basis of the plurality of relationships of correspondence a plurality of relationships of interpolated correspondence expressing correspondence between characteristic values and spectral reflectance distributions of coating colors in which a quantity of at least one component material of all the component materials that are determined on the basis of the relationships of correspondence is varied; selecting a spectral reflectance distribution which is in the relationships of interpolated correspondence corresponding to a coating color to be reproduced when a coating color other than the predetermined coating color is reproduced; and determining quantities of all the component materials by characteristic values that are determined on the basis of the relationships of interpolated correspondence with respect to the selected spectral reflectance distribution, and reproducing the coating color.

In accordance with a second aspect of the present invention, there is provided a method of selecting a coating color, comprising the steps of: with respect to a predetermined coating color on a coated surface which is formed with one or a plurality of layers on an object to be coated and in which each of the layers is formed of at least one component material, determining in advance a plurality of relationships of corespondence between characteristic values constituted by amounts of respective ones of all the component materials constituting the coated surface and a spectral reflectance distribution of the coated surface based on the characteristic values, and determining in advance tristimulus values based on a spectral reflectance distribution of the coated surface based on the characteristic values; estimating on the basis of the plurality of relationships of correspondence a plurality of relationships of interpolated correspondence expressing correspondence between characteristic values and spectral reflectance distributions of coating colors in which a quantity of at least one component material of all the component materials that are determined on the basis of the relationships of correspondence is varied, and determining the tristimulus values based on the spectral reflectance distribution of the coated surface based on characteristic values of the estimated relationships of interpolated correspondence; determining coordinate values on coordinates of a predetermined colorimetric system with respect to each of the tristimulus values and interpolated tristimulus values, and setting a plurality of coordinate values among the determined coordinate values as reference coordinate values for expressing reference colors; and when a tendency of one of the reference colors is to be reflected on an instructed color instructed for reproducing the coating color, selecting the coating color by consecutively selecting coordinate values in a direction from coordinate values specifying the instructed color to the reference coordinate values, starting with proximate coordinate values.

In accordance with a third aspect of the present invention, there is provided a method of selecting a coating color, comprising the steps of: with respect to a predetermined coating color on a coated surface which is formed with one or a plurality of layers on an object to be coated and in which each of the layers is formed of at least one component material, determining in advance a plurality of relationships of corespondence between characteristic values constituted by amounts of respective ones of all the component materials constituting the coated surface and a spectral reflectance distribution of the coated surface based on the characteristic values; estimating on the basis of the plurality of relationships of correspondence a plurality of relationships of interpolated correspondence expressing correspondence between characteristic values and spectral reflectance distributions of coating colors in which a quantity of at least one component material of all the component materials that are determined on the basis of the relationships of correspondence is varied; determining varied-angle characteristics of the coated surface expressing flip-flop relationships between a varied angle when a light-receiving angle is varied during reception of light reflected from the coated surface and brightness at the varied angle, on the basis of the spectral reflectance distributions in the relationships of interpolated correspondence or the spectral reflectance distributions in the relationships of correspondence; and selecting the coated color by selecting the varied-angle characteristic of the coating color to be reproduced from the determined varied-angle characteristics.

In accordance with a fourth aspect of the present invention, there is provided a method of selecting a coating color, comprising the steps of: with respect to a predetermined coating color on a coated surface which is formed with one or a plurality of layers on an object to be coated and in which each of the layers is formed of at least one component material, determining in advance a plurality of relationships of corespondence between characteristic values constituted by amounts of respective ones of all the component materials constituting the coated surface and a spectral reflectance distribution of the coated surface based on the characteristic values; estimating on the basis of the plurality of relationships of correspondence a plurality of relationships of interpolated correspondence expressing correspondence between characteristic values and spectral reflectance distributions of coating colors in which a quantity of at least one component material of all the component materials that are determined on the basis of the relationships of correspondence is varied; determining a particle-size distribution of each of the component materials for each of the characteristic values in the relationships of correspondence and the characteristic values in the relationships of interpolated corre-

spondence, and determining depth indexes specifying the depth of coating colors on the basis of the spectral reflectance distributions in the relationships of interpolated correspondence or the spectral reflectance distributions in the relationships of interpolated correspondence and the determined particle size distribution; and selecting the coating color by selecting from the selected depth indexes.

In accordance with a fifth aspect of the present invention, comprising the steps of: estimating on the basis of a plurality of relationships of correspondence determined in advance a relationship of correspondence between a spectral reflectance distribution and a characteristic value of the selected coating color (this coating color which is selected by the method of the selecting a coating color in accordance with at least one of the second, third , and fourth aspects of the invention); and reproducing the coating color by determining a quantity of each of all the component materials by characteristic values which are determined from the estimated relationship of correspondence.

In accordance with the first aspect of the invention, a plurality of relationships of correspondence are determined in advance with respect to a predetermined coating color on a coated surface. This coated surface is formed with one or a plurality of layers on an object to be coated, and each of its layers is formed of at least one component material. A plurality of relationships of correspondence between characteristic values constituted by amounts of respective ones of all the component materials constituting the coated surface and a spectral reflectance distribution of the coated surface based on the characteristic values are determined in advance. These relationships of correspondence can be determined by, for instance, making use of sample coated plates whose spectral reflectances, pigments and the like are already known. A plurality of relationships of interpolated correspondence, which express correspondence between characteristic values and spectral reflectance distributions of coating colors in which a quantity of at least one component material of all the component materials that are determined on the basis of the relationships of correspondence is varied, are estimated by interpolation or the like on the basis of the plurality of relationships of correspondence. Accordingly, the relationships of interpolated correspondence between characteristic values and spectral reflectance distributions can be determined with respect to a desired coating color on the basis of a plurality of predetermined relationships of correspondence. Here, when a coating color other than the predetermined coating color is to be reproduced, a spectral reflectance distribution which is in the relationships of interpolated correspondence corresponding to the coating color to be reproduced is selected. If quantities of all the component materials, including such as color materials and bright materials, are determined by characteristic values that are determined on the basis of the relationships of interpolated correspondence with respect to this selected spectral reflectance distribution, it is possible to reproduce the composition of the coated surface and a desired coating color on a CRT or by means of a color-material mixing apparatus or the like.

In accordance with the second aspect of the invention, a plurality of relationships of corespondence between characteristic values constituted by amounts of respective ones of all the component materials constituting the coated surface in the second aspect of the invention and a spectral reflectance distribution of the coated surface based on the characteristic values are determined in advance. At the same time, tristimulus values based on a spectral reflectance distribution of the coated surface based on the characteristic values are determined in advance. These tristimulus values include values represented by a colorimetric system such as the XYZ colorimetric system, and can be represented by coordinate values on chromaticity coordinates. In addition, the Munsell color system can be also used. on the basis of the plurality of relationships of correspondence, a plurality of relationships of interpolated correspondence, described in relation to the second aspect of the invention, are estimated. At the same time, the tristimulus values based on the spectral reflectance distribution of the coated surface based on characteristic values of the estimated relationships of interpolated correspondence are determined. Coordinate values with respect to these tristimulus values and interpolated tristimulus values are determined on coordinates of a predetermined colorimetric system, such as the XYZ colorimetric system, and a plurality of coordinate values among the determined coordinate values are set as reference coordinate values for expressing reference colors. As these reference colors, it is preferable to set basic colors that are used in coating or printing, such as red, blue, yellow, green, magenta, cyan, white, and black. When a tendency of one of the reference colors is to be reflected on an instructed color instructed for reproducing the coating color, if the coating color is selected by consecutively selecting coordinate values in a direction from coordinate values specifying the instructed color to the reference coordinate values, starting with proximate coordinate values, then the coating colors corresponding to the selected coordinate values gradually come to reflect the tendency of the reference color. Accordingly, if the quantities of all the component materials including such as color materials and bright materials are determined on the basis of the characteristic values of the coating color corresponding to the selected coordinate values, it is possible to reproduce a desired coating color on which the tendency of the reference color is reflected.

Here, there are cases where a sensuous flip-flop texture, such as a modulated texture of light and darkness, is included among the coating colors desired by the designer or the like. Accordingly, in accordance with the third aspect of the invention, varied-angle characteristics of the coated surface expressing flip-flop relationships between a varied angle when a light-receiving angle is varied during reception of light reflected from the coated surface and brightness at the varied angle, are determined on the basis of the spectral reflectance distributions in the relationships of interpolated correspondence or the spectral reflectance distributions in the relationships of correspondence. Since the sensu-

ous flip-flop texture can be expressed by this varied-angle characteristic, if the varied-angle characteristic of the coating color to be reproduced is selected from the determined varied-angle characteristics, it is possible to select a coating color on which the flip-flop texture is reflected. Accordingly, if the quantities of all the component materials, including such as color materials and bright materials, are determined on the basis of the characteristic values of the coating color corresponding to the selected varied-angle characteristic, it is possible to reproduce a coating color on which the sensuous flip-flop texture desired by the designer or the like is reflected.

In addition, sensuous instructions such as "a color having a texture of depth" are also included among the coating colors desired by the designer or the like. Accordingly, in accordance with the fourth aspect of the invention, a particle-size distribution of each of the component materials for each of characteristic values in the relationships of correspondence determined in advance and characteristic values in the relationships of interpolated correspondence. Then, depth indexes specifying the depth of coating colors are determined on the basis of the spectral reflectance distributions in the relationships of interpolated correspondence or the spectral reflectance distributions in the relationships of interpolated correspondence and the determined particle size distribution. Accordingly, sensuous depths corresponding to the selected depth indexes can be expressed as amounts, and if the plurality of depth indexes thus determined are selected, it is possible to select a coating color exhibiting a desired depth. Hence, if the quantities of all the component materials, including such as color materials and bright materials, are determined on the basis of the characteristic values of the coating color corresponding to the selected depth index, it is possible to reproduce a coating color having a desired depth desired by the designer or the like.

In addition, in the fifth aspect of the invention, at least one of a coating color on which the tendency of a reference color is reflected, a coating color having a varied-angle characteristic expressing a flip-flop relation, and a coating color having a desired texture of depth is selected. Then, a relationship of correspondence between a spectral reflectance distribution and a characteristic value of this selected coating color selected is estimated on the basis of a plurality of relationships of correspondence determined in advance. Accordingly, even in a case where coating colors which are desired by the designer or the like and are expressed sensuously are combined, if the quantity of each of all the component materials, such as color materials and bright materials, are determined by characteristic values which are determined from the estimated relationship of correspondence, it is possible to faithfully reproduce the desired, sensuously expressed coating color.

In accordance with the first aspect of the invention, it is possible to determine the characteristic values of a surface coated with a coating color constituted by a plurality of component materials including color materials and bright materials. Therefore, there is an advantage in that even in the case of a coated surface containing bright materials, such as metal pearl mica, which do not conform to the Kubelka-Munk's theory, it is possible to accurately reproduce a desired color as a coating color.

In accordance with the second aspect of the invention, colors midway in a direction from an instructed color to a reference color can be selected consecutively. Hence, there is an advantage in that, even if a coating color tinged with a tone is instructed by the designer or the like, such as a more reddish color, it is readily possible to select a coating color matching the sense of the designer or the like. In addition, since the characteristic values of a coated surface of a coating color selected as a coating color matching the sense of the designer or the like can be determined, there is an advantage in that a desired coating color tinged with a tone can be reproduced accurately.

In accordance with the third aspect of the invention, since it is possible to determine and select varied-angle characteristics of a coated surface expressing the relationship between the varied angle, which allows the sensuous flip-flop texture to be expressed, and the brightness at the varied angle, there is an advantage in that it is possible to select a coating color on which a modulated texture of light and shade desired by the designer or the like is reflected. In addition, since it is possible to determine the characteristic values of a coated surface of the coated color selected as a coating color matching the sense of flip-flop texture of the designer or the like, there is an additional advantage in that it is possible to accurately reproduce the coating color incorporating the desired flip-flop texture.

In accordance with the fourth aspect of the invention, since the depth indexes expressing the depth of coating colors are determined on the basis of the particle-size distributions of the component materials for each characteristic value, there is an advantage in that it is possible to select a coating color having a desired texture of depth, which is sensuously expressed as depth, as the coating color desired by the designer or the like. Moreover, since a coated surface can be formed on the basis of the characteristic values of the coating color with respect to the depth index, there is an advantage in that a coating color presenting a sensuous texture of depth desired by the designer or the like can be reproduced.

In accordance with the fifth aspect of the invention, since relationships of correspondence with respect to a coating color with the tendency of a reference color reflected thereon, a coating color having a flip-flop texture, or a coating color having a desired texture of depth can be selectively estimated, there is an advantage in that, even if sensuous coating colors desired by the designer or the like are combined, it is possible to faithfully reproduce the desired sensuous color as the coating color.

The above and other objects, features and advantages of the present invention will become more apparent from

the following detailed description of the invention when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 a schematic diagram of a color reproducing apparatus for reproducing a coating color, including a personal computer, in accordance with a first embodiment of the present invention;
Fig. 2 is a conceptual diagram explaining a configuration of a gonio-spectrophotometer;
Fig. 3 is a diagram illustrating an orthogonal coordinate system for explaining a varied angle α used in the first embodiment;
Fig. 4 is a characteristic diagram illustrating a varied-angle characteristic of a spectral reflectance factor of a coated surface;
Figs. 5A to 30C are image diagrams illustrating configurations of coated surfaces, in which Fig. 5A shows a metallic coated surface, Fig. 5 B shows a pearl-mica coated surface, and Fig. 5 C shows a solid-coated surface;
Fig. 6 is a characteristic diagram illustrating reflectance characteristics of a plurality of coating colors when the varied angle α is 45°;
Fig. 7 is a characteristic diagram illustrating the relationship between the varied angle α and brightness Y with respect to a plurality of coating colors;
Fig. 8 is an image diagram illustrating reflectance characteristics with respect to coating colors in a three-dimensional coordinate system having reflectance, varied angle, and wavelength as axes;
Fig. 9 is a flowchart illustrating the flow of a control main routine for reproducing a coating color in accordance with the first embodiment;
Fig. 10 is a flowchart illustrating the details of Step 500 in Fig. 9 in accordance with the first embodiment;
Fig. 11 is a flowchart illustrating the flow of color reproduction processing (Step 700) in accordance with the first embodiment;
Figs. 12 A to 12C are image diagrams illustrating the flow of coating-color reproduction processing shown in Fig. 11;
Fig. 13 is a diagram illustrating correspondence between a characteristic value vector VX and a reflectance vector VR;
Fig. 14 is a flowchart illustrating the details of Step 500 in Fig. 9 in accordance with a second embodiment;
Fig. 15 is a CIE x-y chromaticity diagram including primary colors determined in accordance with the second embodiment;
Fig. 16 is a schematic diagram of a neural network apparatus in accordance with the second embodiment;
Fig. 17 is an image diagram illustrating a configuration of the network of the network apparatus;
Fig. 18 is an image diagram illustrating adjacent layers in the network;
Fig. 19 is a flowchart illustrating the flow of a control main routine for reproducing a coating color in accordance with a third embodiment;
Fig. 20 is a flowchart illustrating the flow of a coating-color selection routine in accordance with a fourth embodiment;
Fig. 21 is a diagram illustrating the Munsell color system;
Fig. 22 is a diagram illustrating the CIE chromaticity coordinates;
Fig. 23 is a diagram illustrating correspondence between the Munsell color system and the CIE chromaticity coordinates;
Fig. 24 is a diagram for explaining that points other than plotted points are obtained by interpolation;
Fig. 25 is a flowchart illustrating the flow of a process in which a tone is imparted to a coating color as instructed, in accordance with a fifth embodiment;
Fig. 26 is a distribution diagram of coating colors in which a plurality of actual coating colors are plotted on the chromaticity coordinate plane;
Fig. 27 is a diagram illustrating areas of color which can be formed on the chromaticity coordinate plane on a monitor and in a paint;
Fig. 28 is a diagram (chromaticity coordinate diagram) illustrating a process for imparting a tone to an instructed coating color;
Fig. 29 is a flowchart illustrating processing for obtaining a coating color on which metallic material and mica material are reflected in accordance with an sixth embodiment;
Fig. 30 is an image diagram illustrating a three-dimensional space of a coordinate system having as axes quantities of component materials governing a coating color, a quantity of metallic material, and a quantity of mica material;
Fig. 31 is a diagram illustrating a region where each quantity is variable;
Fig. 32 is a flowchart illustrating a main routine for obtaining a coating color having a flip-flop texture in accordance with a fifth embodiment;

Fig. 33 is a diagram concerning a reflectance and illustrates a process for obtaining the reflectance;

Fig. 34 is a diagram illustrating varied-angle characteristics;

Fig. 35 is a flowchart illustrating the flow of processing for obtaining a coating color having a flip-flop texture in accordance with the fifth embodiment;

Fig. 36 is a diagram illustrating spectral reflectance characteristics for explaining mirror reflectance;

Fig. 37 A is a diagram illustrating the varied-angle characteristic;

Fig. 37B is an image diagram illustrating a configuration of a coated surface to be measured;

Fig. 38 is a diagram illustrating varied-angle characteristics;

Figs. 39 A and 39B are image diagrams with and without a perspective of an image, respectively;

Figs. 40 A and 40B are diagrams illustrating characteristic curves of particle-size distributions of two bright materials, respectively;

Fig. 41 is a flowchart illustrating the flow of processing for obtaining a coating color having a texture of depth in accordance an ninth embodiment;

Fig. 42 is a flowchart illustrating the flow (Step 502 in Fig. 19) of a second NNW method in accordance with the third embodiment; and

Fig. 43 is a flowchart illustrating the flow (Step 502 in Fig. 19) of a third NNW method in accordance with the third embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A description will be given of a first embodiment. In this embodiment, the present invention is applied to a color reproducing apparatus for reproducing a coating color. In this embodiment, as shown in Fig. 1 , a color-material mixing apparatus 20 having an automatic measuring device is used instead of the color copying apparatus 18. The personal computer 16 is comprised of the keyboard 10 for entering data and the like, the main unit 12 of the computer for computing and outputting relevant data for generating a desired coating color in accordance with a program stored in advance, and the CRT 14 for displaying a coating color or the like which is the result of computation by the main unit 12 of the computer. The color-material mixing apparatus 20 generates a paint by mixing a plurality of color materials after measuring the color materials such as pigments by a measuring instrument, e.g., an electronic force balance, in response to signals outputted from the personal computer 16.

Here, in this embodiment, to reproduce a coating color, physical amounts for specifying the coating color are set as follows.

As already mentioned in the description of the related art, if the spectral reflectance of the coated surface can be specified, the tristimulus values and the like of the color can be determined, with the result that its surface color can be specified. Therefore, in this embodiment, the spectral reflectance of an original or object surface is used to realize color reproduction for displaying a color image or the like and for specifying a faithful coating color on the object surface. It should be noted that values of this spectral reflectance, when measured with respect to surfaces of samples having complicated configurations, such as fibers and metallic coatings, can vary depending on the direction of light reception of the measuring instrument. In this embodiment, therefore, a spectral reflectance factor is used which is a three-dimensional reflectance obtained by varying the angle of incidence upon a sample and the light-receiving angle of a light-receiving element for receiving the light reflected by the sample.

The reflectance of a sample having a flat surface can be usually measured (photometrically measured) by a gonio-spectrophotometer 24. This measured reflectance is referred to as the spectral reflectance factor, which will be simply referred to hereafter as the reflectance R.

As shown in Fig. 2, the gonio-spectrophotometer 24 has a light source 28 and a light-receiving unit 26. In the case of the gonio-spectrophotometer 24, a plane which includes an incident optical axis 32 of the light directed from the light source 28 toward a measuring point Ob of a sample 30 and a optical axis 34 of reflection in the direction of regular reflection when the light of the incident optical axis 32 is regularly reflected at the measuring point Ob, is defined as an incident plane D_1. In this gonio-spectrophotometer 24, the axis connecting the light-receiving unit 26 and the measuring point Ob is set as a measuring optical axis 36. This gonio-spectrophotometer 24 has a mechanism (not shown) in which the light-receiving unit 26 is moved three-dimensionally such that the measuring optical axis 36 is included within the incident plane D_1.

The reflectance R is a function of an angle α (unit: degree; hereafter referred to as a varied angle α) formed by the reflection optical axis 34 and the measuring optical axis, i.e., an angle α of the direction of regular reflection with respect to the light-receiving unit, and a wavelength λ (unit: nm) of light, and can be expressed by the following Formula (14):

$$R(\alpha, \lambda) \tag{14}$$

where the varied angle α is 0° when the reflection optical axis 34 and the measuring optical axis 36 coincide with each

other. In addition, the sign of the varied angle α which is obtained from the position of the light-receiving unit 26 rotated clockwise from the direction of regular reflection toward the light source (in the direction of arrow indicating the varied angle α in Fig. 2) will be set as a positive sign.

As shown in Fig. 3, the varied angle α can be determine in a rectangular coordinate system using the incident plane and the like. In other words, a normal direction \$N of the sample 30, an incident direction \$L which is an azimuth between the sample 30 and the light source 28, a light-receiving direction \$R in which the light is directed from the sample 30 toward the light-receiving unit 26, and a regularly reflecting direction \$P in which the light is regularly reflected from the sample 30 are set. Then, a plane which includes the normal direction \$N and the regularly reflecting direction \$P is set as the incident plane D_1, while a plane which includes the normal direction \$N and the light-receiving direction \$R is set as a light-receiving plane D_2. As a result, an angle θ_1 formed by the normal direction \$N and the incident direction \$L, an angle θ_2 formed by the normal direction \$N and the light-receiving direction \$R, and an angle θ_3 formed by the incident plane D_1 and the light-receiving plane D_2 are set. In addition, in a case where the surface of the sample 30 is directional (e.g., in the case of fabrics and brushing-finished surfaces), an angle at which the reference direction of the sample surface (coated surface) (a direction \$A in Fig. 28) moves away from the incident plane D_1 with the measuring point Ob set as a center is set as an angle θ_4. Accordingly, the reflectance R in Formula (14) above can be expressed as a general formula by the following Formula (15):

$$R(\lambda, \theta_1, \theta_2, \theta_3, \theta_4) \tag{15}$$

where

θ_1: incident angle of the light source (deg)
θ_2: light-receiving angle (deg)
θ_3: azimuth angle (deg)
θ_4: rotational angle (deg)

Formula (15) above has four angular parameters denoted respectively by θ_1, θ_2, θ_3, and θ_4. It is known that the distribution of intensity of reflected light (a distribution in which the intensity of reflected light is expressed by the distance with an irradiating point set as a center) from a surface coated with a general paint always shows spherical symmetry having similar figures with the regularly reflecting direction \$P as an axis, irrespective of the incident angle θ_1 of the incident light.

Fig. 4 shows a varied-angle characteristic diagram of the spherical reflectance factor and illustrates the spherical symmetry of the light reflected from a surface coated with a general paint (a metallic coated surface). In the drawing, as shown in Table 1 below, the varied-angle characteristic when the varied angle α is varied in the positive direction when the incident angle θ_1 is 0° is set as a characteristic AP, while the varied-angle characteristic when the varied angle α is varied in the negative direction is set as a characteristic AN. Similarly, when the incident angle θ_1 is 15°, 30°, 45°, and 60°, varied-angle characteristics when the varied angle α is varied in the positive direction are set as characteristics BP, CP, DP, EP, and FP, while varied-angle characteristics when the varied angle α is varied in the negative direction are set as characteristics BN, CN, DN, and EN.

Table 1

Incident angle θ_1		0°	15°	30°	45°	60°	75°
Varied angle α	+ direction	AP	BP	CP	DP	EP	FP
	—direction	AN	BN	CN	DN	EN	--

As can be appreciated from Fig. 4, the varied-angle characteristics are substantially symmetrical irrespective of the incident angle. It should be noted that, when the incident angle was 75°, a measurement error occurred due to a sheen phenomenon caused by a reference white plate, so that the listing was omitted here.

Accordingly, the reflectance of the surface coated with the paint can be expressed by the reflectance $R(\alpha, \lambda)$ as a function of the varied angle α between the regularly reflecting direction \$P and the light-receiving direction \$R, as shown in Formula (14) above. For instance, if the angular conditions other than the light-receiving angle θ_2 are fixed to predetermined values (θ_1 = 60°, θ_3 = 0°, and θ_4 = 0°), and the varied angle α is varied in the range 0° to 90° (in this case, $\alpha = \theta_1 - \theta_2$), and if the reflectance $R(\alpha, \lambda)$ is measured by the gonio-spectrophotometer, the reflectance $R(\alpha, \lambda)$ can be determined in the angular range $0° < \alpha < 90°$.

Also, if the reflectance $R(\alpha, \lambda)$ is set under the angular conditions listed below, the reflectance $R(\alpha, \lambda)$ can be deter-

mined in the angular range $-30° < \alpha < 150°$.

Angular Conditions:

$$R(\alpha, \lambda) = R(-\alpha, \lambda)\ (-30° < \alpha < 0°)$$
$$= R(90°, \lambda)\ (90° < \alpha < 150°)$$

It should be noted, in the description that follows, the reflectance $R(\alpha, \lambda)$ in which the varied angle α is computed from the relation between the regularly reflecting direction $P and the light-receiving direction $R is used even in cases other than the aforementioned angular conditions ($\theta_1 = 60°$, $\theta_3 = 0°$, and $\theta_4 = 0°$).

As shown in Figs. 5A to 5C, the coated surface of a sample whose surface is coated is comprised of various substances including color pigments governing the color, bright materials such as metal pearl mica, and clear coat materials on the surfaces.

As shown in Fig. 5A, a coated surface formed by a metallic coating is comprised of a clear coat layer 40, a metallic base layer 42, an intermediate coat layer 44, and an electrodeposited layer 46. The metallic base layer 42 includes a pigment 54 and aluminum 56. As shown in Fig. 5B, a coated surface formed by a pearl mica coating is comprised of a clear coat layer 40, a mica base layer 48, a color base layer 51, an intermediate coat layer 44, and an electrodeposited layer 46. The mica base layer 48 includes a titanized mica pigment 58. As shown in Fig. 5C, a coated surface formed by a solid coating is comprised of a top coat layer 53, an intermediate coat layer 44, and an electrodeposited layer 46. The top coat layer 53 includes a coloring pigment 60.

Fig. 6 shows the relationship between the varied angle α and brightness Y (Y is determined by Formula (38) which will be described later). As can be appreciated from the drawing, the rate of change of the reflectance R becomes slower in the order of maroon, crystal coral, camel beige, pale green, and grape blue which are used as coating colors. In addition, Fig. 7 shows the relationship of the reflectance $R(45°, \lambda)$ when the varied angle α is 45°. It can be seen that brightness at a predetermined wavelength varies depending on the kind of the coated surface.

Thus, the characteristic of the reflectance $R(\alpha, \lambda)$ varies due to the difference in the arrangement of the coated surface, and is, at the same time, affected by the kind and quantity of pigment and bright material. Accordingly, to specify these coated surfaces, in this embodiment, by assuming that component materials which make up the coated surface are x_1, x_2, ... and that the size of each component material x_i (i = I, 2, ...) is a quantity q_1 (kg), a characteristic value vector VX representing the coated surface is defined as shown in the following Formula (16):

$$VX = (x_1[q_1], x_2[q_2], ...) \tag{16}$$

Since the reflectance $R(\alpha, \lambda)$ of the coated surface formed by this characteristic value vector VX is related to the characteristic value vector VX, the reflectance $R(\alpha, \lambda)$ can be expressed by the following Formula (17):

$$R(\alpha, \lambda, VX) \tag{17}$$

In this embodiment, since the case in question is the reproduction of a coating color, the characteristic value vector VX shown in the following Formula (18) is considered by taking into consideration only the component materials (pigment and the like) governing the color among the elements of the characteristic value vector VX and by assuming only e component materials related to the color:

$$VX = (x_1[q_1], x_2[q_2], ..., x_e[q_e]) \tag{18}$$

In this embodiment, it is basically assumed that a bright material which, although essentially achromatic, is imparted a color to the extent of substantially changing the color of the pigment, such as some special colored mica, is not used as a component material.

Although, in the above, a description has been given of the reflectance $R(\alpha, \lambda, VX)$, which is based on the continuous characteristics of the varied angle α and the wavelength λ as elements related to the characteristic value vector VX, the reflectance $R(\alpha, \lambda, VX)$ can be handled approximately, as will be described below.

First, the varied angle α (0° to 90°) is appropriately divided such as by dividing it into [n - 1] parts at equal intervals by a boundary value α_j($j = 1, 2, ..., n, 0° = \alpha_1 < \alpha_2 < ... < \alpha_n = 90°$) or by dividing into small parts the range thereof where the change of reflectance is abrupt. It should be noted that it is preferable to provide this appropriate division at intervals of 1° to 5° in such a manner as to obtain 19 to 91 pieces of data.

Similarly, with respect to the wavelength λ as well, the visible wavelength is considered as falling within a wavelength band of, for example, 380 (nm) $\leq \lambda \leq$ 720 (nm), and this visible wavelength band is appropriately divided into [m - 1] regions by means of boundary wavelengths λ_k ($k = I, 2, ..., m$; $380\text{ nm} = \lambda_1 < \lambda_2 ... < \lambda_m = 720\text{ nm}$). It should be noted that it is preferable to provide this appropriate division of the wavelength band at intervals of 10 to 20 nm in such

a manner as to obtain 18 to 35 pieces of data.

Here, by assuming that the reflectance where $\alpha = \alpha_j$ and $\lambda = \lambda_k$ is a unit reflectance $R_{jk}(VX)$, a unit vector $VR_j(VX)$ in units of divided angle is defined, as shown in the following Formula (19):

$$VR_j(VX) = (R_{j1}(VX), R_{j2}(VX), ..., R_{jm}(VX)) \tag{19}$$

It is assumed that interpolation is provided between these respective unit reflectances $R_{jk}(VX)$, and the reflectance $R(\alpha, \lambda, VX)$ can be approximated by discrete unit vectors $VR_j(VX)$, i.e., VR_1, VR, ..., VR_n.

Namely, as shown in Fig. 8, in a three-dimensional coordinate system having the reflectance $R(\alpha, \lambda, VX)$, the varied angle α, and the wavelength λ as axes, the reflectance $R(\alpha, \lambda, VX)$ becomes a continuous surface 71 such as a curved surface. The continuous surface 71 representing the reflectance $R(\alpha, \lambda, VX)$ can be determined by interpolation from the plurality of discrete points included in this continuous surface 71. Consequently, the reflectance $R(\alpha, \lambda, VX)$ can be approximated from the plurality of unit vectors $VR_j(VX)$ included in the continuous surface 71.

Accordingly, the reflectance $R(\alpha, \lambda, VX)$ with respect to the coating color can be approximated from the discrete unit vectors $VR_j(VX)$ shown in Formula (19) above. In this embodiment, the relationship between the characteristic value vector VX and the unit vector $VR_j(VX)$ which is discrete data is set as a normalized value. This normalized value can be obtained by forming an actual coated plate based on the characteristic value vector VX and by measuring the reflectance.

Next, a description will be given of the operation of this embodiment. In cases where a user desires a new reflectance (hereafter referred to as a new reflectance $R^*(\alpha, \lambda)$) on the basis of an image color assumed by a designer or the like or on the basis of an existing reflectance $R(\alpha, \lambda, VX)$, if this new reflectance $R^*(\alpha, \lambda)$ is determined, it is possible to visually confirm the color and texture of the coated surface by the use of a color graphics apparatus and the like (refer to Japanese Patent Application Laid-Open No. 1151/1989). As such, in this embodiment, a description will be given of a case where a characteristic value vector VX*, which is a quantity of a paint or the like, is extimated from a desired new reflectance $R^*(\alpha, \lambda)$ on the basis of the image color assumed by the designer or the like or on the basis of an existing reflectance R.

Namely, the new reflectance $R^*(\alpha, \lambda)$ is a reflectance which is newly generated, and the kinds and quantities of pigments and bright materials for realizing the reflection characteristic of the reflectance $R^*(\alpha, \lambda)$ are unknown. Hence, to reproduce the coating color by means of the new reflectance R*, it suffices to determine a characteristic value vector VX* corresponding to the new reflectance R*, as shown in the following Formula (20):

$$VX^* = (x_1[q_1]^*, x_2[q_2]^*, ..., x_e[q_e]^*) \tag{20}$$

When an unillustrated power switch of the color reproducing apparatus constituted by the personal computer 16 and the like is turned on, a main routine for reproducing a coating color, shown in Fig. 9, is executed.

In Step 500, the aforementioned normalized values are set. Specifically, the operation proceeds to Step 510 shown in Fig. 10 to define the characteristic value vectors VX on the basis of the component materials x_i such as color materials used in the color mixing apparatus 20. Since the characteristic value vectors VX* themselves for obtaining the new reflectance $R^*(\alpha, \lambda)$ is still unknown, in Step 510, the quantity q_i of each component material x_i is set by a random number or to a maximum value.

In an ensuing Step 512, the quantity q_i of each component material x_i of the characteristic value vector VX is appropriately divided into [P + 1] parts by means of boundary values q_{iA} ($1 \le A \le P$, $q_{i1} < q_{i2} < ... < q_{iP}$). As a result, each of the component quantities q_1, q_2, ..., q_e is developed into P quantities in which the component quantity increases or decreases in stages. Therefore, the combinations of the characteristic value vectors VX based on these component quantities q_{iP} become $L = P^e$ combinations, as shown in the following Formula (20-1).

$$
\begin{array}{l}
\begin{array}{cccccc}
q_1 & q_2 & \cdots & q_i & \cdots & q_e \\
(x_1) & (x_2) & \cdots & (x_i) & \cdots & (x_e)
\end{array} \\
\hline
\text{P groups} \left\{ \begin{array}{cccccc}
q_{11} & q_{21} & \cdots & q_{i1} & \cdots & q_{e1} \\
q_{12} & q_{22} & \cdots & q_{i2} & \cdots & q_{e2} \\
\vdots & \vdots & & \vdots & & \vdots \\
q_{1P} & q_{2P} & \cdots & q_{iP} & \cdots & q_{eP}
\end{array} \right. \quad \cdots\cdots \ (20\text{-}1) \\
\underbrace{\hphantom{q_{11} \quad q_{21} \quad \cdots \quad q_{i1} \quad \cdots \quad q_{e1}}}_{\text{L combinations}}
\end{array}
$$

In an ensuing Step 514, a characteristic value vector VX_h ($h = 1, 2, \ldots, L$) is determined for each combination of L component quantities q_{iP} In other words, each characteristic value vector VX_h with the component materials changed is determined by consecutively varying the quantity of each component material $x_1, x_2, \ldots, x_e$, as shown in the following Formula (20-2):

$$
\begin{array}{l}
VX_1 = (x_1\ [q_{11}],\ x_2\ [q_{21}],\ \ldots,\ x_e\ [q_{e1}] \\
VX_2 = (x_1\ [q_{12}],\ x_2\ [q_{21}],\ \ldots,\ x_e\ [q_{e1}] \\
VX_3 = (x_1\ [q_{13}],\ x_2\ [q_{21}],\ \ldots,\ x_e\ [q_{e1}] \\
\quad \vdots \\
VX_L = (X_1\ [q_{1P}],\ x_2\ [q_{2P}],\ \ldots,\ x_e\ [q_{eP}]
\end{array}
\quad \cdots\cdots \ (20\text{-}2)
$$

In an ensuing Step 516, a paint is generated in which color materials and the like are mixed on the basis of the quantities of the component materials of the characteristic value vectors VX_h thus determined, and the reflectance $R_h(\alpha, \lambda, VX_h)$ of the coated surface of the coated plate formed by coating a plate with the generated paint is determined by actual measurement (refer to Formula (20-3) below).

$$
\begin{array}{lll}
VX_1 & \rightarrow & R_1\ (\alpha,\ \lambda,\ VX_1) \\
VX_2 & \rightarrow & R_2\ (\alpha,\ \lambda,\ VX_2) \\
\vdots & & \vdots \\
VX_L & \rightarrow & R_L\ (\alpha,\ \lambda,\ VX_L)
\end{array}
\qquad \ldots\ldots (20\text{-}3)
$$

It should be noted that, to determine this reflectance $R_h(\alpha, \lambda, VX_h)$ means to obtain a plurality of (nm) unit reflectances R_{jk} when the varied angle α and the wavelength λ are appropriately divided, as described above.

Upon completion of the processing of setting normalized values in Step 500 in the above-described manner, the operation proceeds to Step 600 in which the new reflectance $R^*(\alpha, \lambda)$ desired by the designer or the like is read. The new characteristic value vectors VX^* $(x_1^*, x_2^*, ..., x_e^*)$ corresponding to this arbitrary new reflectance $R^*(\alpha, \lambda)$, i.e., the quantities of component materials such as color materials, are computed in Step 700. In Step 700, the composition and quantities are computed from reflectances and characteristic value vectors which are in known relationships, by using a method of using an inverse estimation method based on interpolation, which has already been proposed by the present applicant (Japanese Patent Application No. 196082/1993).

In this case, characteristic value vectors $VX = (x_1, x_2, ..., x_e)$ capable of determining the quantities of e component materials are set as an input, while data on nm reflectances concerning the reflectance $R(\alpha, \lambda, VX)$ are set as an output. These nm data which are an output are set as a reflectance vector VR shown in the following Formula (21):

$$VR = (R_{11}(VX), R_{12}(VX), ..., R_{nm}(VX)) \tag{21}$$

If it is assumed that a transformation for obtaining an output of the reflectance vector VR from the input of the aforementioned characteristic value vector VX is a function f, the transformation can be expressed as shown in Formula (22) below. An inverse problem of the relationship expressed by this Formula (22) can be handled as shown in Formula (23) below.

$$f: VX \rightarrow VR \tag{22}$$

$$f^{-1}VR \rightarrow VX \tag{23}$$

Referring to the flowchart shown in Fig. 11, a brief description will be given of the details of Step 700. In Step 710, reflectances R (output values Oi in Figs. 12A to 12 C) with respect to a plurality of (in this embodiment, 5^3) characteristic value vectors VX (input values Si at sample points in Figs. 12 A to 12C) are determined (see Fig. 12A). Namely, this relationship is determined by measuring the reflectance of a coated plate for which the quantities of component materials are already known. In this Step 710, processing similar to that for setting normalized values in Step 500 is carried out. In Step 712, correspondence between an interpolating point SIi (i: 1, 2, ...) with respect to a discrete input value Si and an estimated output value OIi with respect to this interpolating point SIi is calculated by performing interpolation on the basis of the relationship of correspondence between the input value Si and the output value Oi (Fig. 12B). In an ensuing Step 714, the output value Oi or the estimated output value OIi, which is closest to an output value to be obtained and corresponding to a desired color (the output value being the data on the reflectance of the coating color to be reproduced, i.e., the data indicated by a mark * in Fig. 12C), is selected, and an input value Si or an interpolating point SIi (i.e., the characteristic value vector VX) corresponding to the selected value (Oi or OIi) is determined (see Fig. 12C).

What should be noted here is that, as for a reflectance vector VR* falling outside the value region of the reflection vector VR formed with respect to all the combinations of the characteristic value vector VX $(VX_1, ..., VX_L)$, there is no solution of the characteristic value vector VX, i.e., the reflectance vector VR* cannot be generated The expression "falling outside the value region of the reflection vector VR" refers to cases where, as shown in Fig. 13 , when n = i and m = 8, the unit vector $VR_j(VX)$ falls outside the region Area that $VR_j(VX)$ can assume due to the change of $VX_1, ..., VX_L$.

In this case, the points A_1, A_2, A_3, A_4, and A_5 are included in the region Area, but the points A_6, A_7, and A_8 are not included in the region Area.

If the characteristic value vector VX* for obtaining the new reflectance $R^*(\alpha, \lambda)$ is found in the above-described manner, and, in Step 800, signals representing the mixture $x_1[q_1]^*$, $x_2[q_2]^*$, ..., $x_e[q_e]^*$ based on the characteristic value vectors VX* are outputted to the color-material mixing apparatus 20, and the paint is produced by the color-material mixing apparatus 20, it is possible to fabricate a coated object such as a coated plate having a desired reflectance $R^*(\alpha, \lambda)$.

Next, a description will be given of a second embodiment. In the above-described first embodiment, a description has been given of the case where the quantities of component materials are appropriately divided for processing the setting of normalized values. However, in a case where there are a multiplicity of component materials, their combinations become enormously large, which make it impractical to follow this procedure. Accordingly, in the second embodiment, a description will be given of a case where normalized values are determined easily irrespective of the number of the kinds of component materials. It should be noted that since the second embodiment is arranged in a manner similar to that of the first embodiment, identical portions will be denoted by the same reference numerals, and a detailed description thereof will be omitted.

For example, a coating color A which already exists can be expressed by the following characteristic value vector

$$VX = (x_1[q_1], x_2[q_2], ..., x_5[q_5])$$

where

x_1: holiito metallic, coarse (bright material) q_1: 41.19 (g)
x_2: white metallic, fine (bright material) q_2: 4.40 (g)
x_3: tinting black (pigment) q_3: 11.70 (g)
x_4: blue black (pigment) q_4: 6.69 (g)
x_5: indanthrene blue (pigment) q_5: 14.54 (g)

Here, actual coated plates are fabricated by fixing the quantities q_1, q_2 of the component materials (bright materials) x_1, x_2 and by varying the quantities q_3, q_4, q_5 of the component materials x_3, x_4, x_5 as shown below. Next, as shown in the [State A] below, the quantities are varied by 10 g each in six stages so that the respective quantities will not exceed fixed values (e.g., 50 g). Consequently, it is possible to obtain states of 6^3 = 216 coated plates. Accordingly, it is possible to obtain reflectances $R(\alpha, \lambda, VX)$ with respect to 216 characteristic value vectors VX.

[State A]

$$\begin{aligned}(q_3, q_4, q_5) &= (0, 0, 0)\\ &= (0, 0, 10)\\ &= (0, 0, 20)\\ &\vdots\\ &= (50, 50, 50)\end{aligned}$$

If the number (kinds) of component materials x_i, x_{i+1}, ..., x_p increases, it is necessary to fabricate a large number of coated plates for obtaining sample data (unit reflectances), which is not feasible in practical use. For instance, if nine color materials are used, and each of them is divided into six parts of 0, 10, 20, ..., 50 (g), an enormously large number of (a total of $6^9 \cong 1.0 \times 10^7$) combinations of samples (coated plates) would have to be fabricated, so that it is unfeasible to put this procedure to practical use.

Therefore, in this embodiment, the specification of color is simplified as described below. Fig. 15 shows CIE x-y chromaticity coordinates. Points in the drawing are outermost portions when points are plotted on the x-y chromaticity

coordinates at positions corresponding to those colors that can be specified by existing color materials.

When an unillustrated power switch of the color reproducing apparatus constituted by the personal computer 16 and the like is turned on, the main routine shown in Fig. 9 is executed. In Step 500, normalized values are set. Specifically, the operation proceeds to Step 520 shown in Fig. 14 to define the characteristic value vectors VX based on the component materials x_i used in the color-material mixing apparatus 20, and to set primary colors on the basis of colors that can be specified by existing color materials on the x-y chromaticity coordinates. In this embodiment, of the outermost points of colors that can be specified by color materials, points G (green), Y (yellow), R (red), M (magenta), B (blue), and C (cyan) are set as typical points, and a point K corresponding to white is set. Colors corresponding to these points are set as the primary colors.

In an ensuing Step 522, triangular regions each formed by three points including the point K among the aforementioned primary colors are set as subject color regions so as to fabricate sample coated plates. In this case, the subject color regions include six triangles ΔKGY, ΔKYR, ΔKRM, ΔKMB, ΔKBC, and ΔKCG. An arbitrary color can be reproduced by using data (quantities) on the apexes of a triangle including a point at the position corresponding to that color. In short, it is possible to specify colors located at all the positions included in a triangle by varying the respective quantities at the three apexes of the triangle.

In an ensuing Step 524, one of the aforementioned set triangles is selected. For instance, to reproduce a coating color located at the point C1 in Fig. 40, the points K, Y ad G are used as the primary colors, and the variation of the quantities of component materials is processed within ΔKGY. In an ensuing Step 126, the quantities of component materials of the primary colors of the selected triangle are divided appropriately in, for example, six stages, as shown in [State B] below. Hence, with respect to ΔKGY in this case, $6^3 = 216$ combinations are assumed, and sample coated plates are fabricated, respectively. In an ensuing Step 528, the reflectances of these fabricated sample coated plates are actually measured, and the operation proceeds to Step 530.

[State B]

$$
\begin{aligned}
(K, G, Y) &= (0, 0, 0) \\
&= (0, 0, 10) \\
&= (0, 0, 20) \\
&\vdots \\
&= (50, 50, 50)
\end{aligned}
$$

(Note: Here, it is assumed that the quantities of bright materials are fixed.)

In an ensuing Step 530, a determination is made as to whether or not the above-described processing has been completed for all the triangular regions set in Step 522 above, and processing is executed until processing is completed for all the triangles. By so doing, it is possible to fabricate in a small number the sample coated plates for color reproduction with respect to all the color regions that can be specified by the color materials, and normalized values can be easily set irrespective of the number of kinds of the component materials used.

Next, a description will be given of a third embodiment. In the above-described first and second embodiments, unknown characteristic value vectors VX* are determined by a method in which an inverse estimation method based on interpolation is used. In the third embodiment, a solution for the inverse problem (f^{-1}), shown in Formula (23) above, in which an unknown characteristic value vector VX* is determined from a reflectance vector VR, i.e., the estimation of the characteristic value vector VX* with respect to the reflectance $R^*(\alpha, \lambda)$ (R_{11}^*, R_{12}^*, ..., R_{nm}^*), is obtained by using a known neural network method. In other words, a neural network, which has neurons corresponding to the number of reflectances R* as an input layer for inputting the reflectances R* and has neurons corresponding to the number of the characteristic value vector VX* as an output layer for outputting quantities of component materials, and in which the neurons are interconnected by synapses, is learned by a learning process which will be described below, so as to obtain a system for determining known characteristic value vectors VX* from desired reflectances R*.

With respect to the neural network method (hereafter referred to as the NNW method) in the third embodiment, a description will be given of three kinds of examples for estimating characteristic value vectors VX* with respect to reflectances $R^*(\alpha, \lambda)$ by expanding the structure of the neural network to continuous N layers. It should be noted that, since the third embodiment is arranged in a manner similar to those of the first and second embodiments, identical portions will be denoted by the same reference numerals, and a detailed description thereof will be omitted. In addition, since first, second and third NNW methods have substantially similar arrangements, different portions will be described in order. Furthermore, although a description will be given of the neural network method based on learning assisted by a teacher, it is possible to adopt one based on learning not assisted by a teacher.

As shown in Fig. 16, the personal computer 16 has a neural network apparatus 72. The neural network apparatus 72 is comprised of a network 74 and a teacher unit 76. Reflectances R* are inputted to the network 74, which, in turn, outputs estimated characteristic value vectors VX*. A teacher signal TC corresponding to an input reflectance R* and an output signal OC corresponding to an output characteristic value vector VX* are inputted to the teacher unit 76, which, in turn, outputs to the network 74 a correction signal SC obtained from the difference between these inputted signals and the like.

As shown in Fig. 17, in terms of its configuration, the network 74 used in this embodiment is assumed to be of a feed forward (FF) type in which each layer accepts an input only from an immediately preceding layer. The network 74 is comprised of N layers, and neurons 85 (hereafter referred to as units 85) in a number (in this embodiment, nm) corresponding to that of reflectance vectors VR which are input signals are present in an input layer 78. First to nm-th units 85, which are present in the input layer 78, are respectively connected in parallel with all the units 85 which are present in a first layer of an intermediate layer 81, which is an ensuing layer. This intermediate layer 81 has N - 2 layers, and the units 85 that are present in each of these layers are respectively connected in parallel with all the units 85 in an ensuing layer. In addition, an output layer 83 continues from a final layer of the intermediate layer 81, and all the units 85 that are present in the final layer of the intermediate layer 81 are connected in parallel with the respective units 85 of the output layer 83. The units 85 in a number (in this embodiment, e) corresponding to that of component materials, i.e., characteristic value vectors, which are output signals, are present in this output layer 83. It should be noted that, with respect to the following units 85, the order of final units 85 which are present in the input layer 78, the intermediate layer 81, and the output layer 83 is denoted as S_z ($1 \leq Z \leq N$)-th. That is, the final unit of the input layer 78 is S_1 (= nm)-th, while the final unit of the output layer 83 is S_N (= e)-th. In addition, the aforementioned connection may be disconnected during learning which will be described later.

As shown in Fig. 18, referring to an S layer ($1 \leq S \leq N - 1$) and an [S + l] layer, which are adjacent to each other in the network 74, outputs from all the units of the S layer are inputted to a u-th unit of the [S + l] layer. Accordingly, an input in_{S+1} (u) to th u-th unit 85 of the [S + l] layer is shown by the following Formula (24):

$$in_{S+1}(u) = \sum_{v=1}^{S_s} \{w_s(u, v) \cdot out_s(v)\} + t_{S+1}(u) \qquad (24)$$

where

w_S (u, V): coefficient of coupling between a v-th unit in the S layer and th u-th unit in the [S + 1] layer
t_{S+1} (u): offset value

In addition, an output value out_{S+1} (u) of the u-th unit in the [S + 1] layer can be determined by the following Formula (25):

$$out_{S+1}(u) = \mathrm{sigmoid}(\mu_0, in_{S+1}(u)) \qquad (25)$$

where sigmoid() is a sigmoid function shown in the following Formula (26):

$$\mathrm{sigmoid}(\mu_0, X) = \frac{1}{1 + e^{-\frac{2X}{\mu_0}}} \tag{26}$$

where

μ_0: constant

Accordingly, the output of the v-th unit of the S layer can be similarly stated as follows:

$$\mathrm{out}_S(v) = \mathrm{sigmoid}(\mu_0, \mathrm{in}_S(v))$$

Next, an error δ_S (S = 1, 2, ..., N) of each unit in the respective layers in the above-described network 74 is defined as described below.

First, an error δ_{Nv} (v = l, 2, ..., S_N) of the v-th unit in the N-th layer which is the output layer 82 is expressed by the following Formula (27):

$$\delta_{Nv} = [\frac{2}{\mu_0}\{T_v - \mathrm{out}_N(v)\}] \cdot \mathrm{out}_N(v)\{1 - \mathrm{out}_N(v)\} \tag{27}$$

where

T_v: teacher signal TC corresponding to the v-th unit

Next, an error δ_{Su} (u = 1, 2, ..., S_z) of the u-th unit in the S-th layer is expressed by the following Formula (28):

$$\delta_{su} = \left[\frac{2}{\mu_0}\{\sum_{v=1}^{S_z}\{\delta_{(S+1)v} \cdot W_{S+1}(u, v)\}\right] \cdot \mathrm{out}_S(u)\{1 - \mathrm{out}_S(u)\} \tag{28}$$

where

$\delta_{(S+1)v}$: error of the v-th unit in the [S + 1] layer

By using the above formula, correction values of the coupling coefficient and the offset value in Formula (24) can be expressed by the following Formulae (29):

$$\Delta W_S(u, v) = \alpha_S \cdot \delta_{(S+1)v} \cdot \mathrm{out}_S(v) \tag{29}$$

$$\Delta t_{S+1}(u) = \beta_S \cdot \delta_{(S+1)v}$$

where

α_S, β_S: constants

As an example of a leaning method using the above-described neural network, a back propagation method (hereafter referred to as the BP method) is known. The BP method is a method whereby the network 74 is converged, i.e., the system is stabilized, by allowing correction values ΔW_S (u, v) and Δt_{S+1} (u) of the coupling coefficient and the offset value shown in Formulae (29) above to converge.

In the BP method, in the same way as in a known delta rule, there are cases where a minimum value of the error is not determined. To overcome this problem, a moment method and a correction moment method are known, and also known as another method is a constant variation method in which an initial value of the correction value is set to a large value, and the correction value is reduced as the error becomes smaller.

In addition, as methods of correcting the coupling coefficient in the BP method, the following methods are known: a consecutive correction method in which the coupling coefficient is corrected with respect to one input, and a batch correction method in which correction amounts are accumulated and correction is effected en bloc after completion of all inputs.

Next, a description will be given of the operation of this embodiment using a first NNW method. When an unillus-

trated power switch of the color reproducing apparatus constituted by the personal computer 16 and the like is turned on, a main routine for reproducing a coating color, shown in Fig. 19, is executed. In Step 500, the aforementioned normalized values are set. Accordingly, $L = P^e$ combinations of the characteristic value vector VX and the reflectance R(α, λ, VX) are obtained, as shown in Formula (20-2) above.

With respect to reflectances R of combinations (5^3 = 125 sets) of tristimulus values of five kinds each, which become dispersed coordinate values on the x-y chromaticity coordinates, learning is conducted by using known relationships between reflectance vectors VR and characteristic value vectors VX, as described below.

In an ensuing Step 502, the learning of the network 74 is carried out. Namely, the following nm pieces of data on reflectance with respect to the characteristic value vector VX are given as an input of the network 74:

$$R_{11}(VX), R_{12}(VX), \ldots, R_{nm}(VX): VR$$

At the same time, the following e elements (quantities) of the characteristic value vector VX for obtaining the reflectance vector VR are outputted to the teacher unit 76 as teacher signals:

$$x_1[q_1], x_2[q_2], \ldots, x_e[q_e]$$

The teacher unit 76 outputs the correction signal SC while monitoring the characteristic value vector VX and the output of the network as described below. Such processing is carried out with respect to L sets by using the above-described BP method to learn the network 74. This learning process is repeated until a mean square error ε, shown in Formula (30) below, between the characteristic value vector VX, which is a targeted value, and the output value (a characteristic value vector consisting of the quantity of a component material) of the network converges or becomes sufficiently small. The coupling coefficient w_S (u, v) and the offset t_{S+1} (u) at this time are determined.

$$\varepsilon = \frac{1}{L} \cdot \Sigma\, |VX - VX'|^2 \tag{30}$$

When the process of learning the network 74 is thus completed, the operation proceeds to Step 600 to read a new reflectance R*(α, λ) desired by the designer or the like. In an ensuing Step 702, an output $x_1[q_1]^*$, $x_2[q_2]^*$, ..., $x_e[q_e]^*$ of the network 74 with respect to desired reflectance data R_{11}^*, R_{12}^*, ..., R_{nm}^* is obtained by using the aforementioned coupling coefficient and offset value. If the characteristic value vector VX* for obtaining the new reflectance R*(α, λ) is found in the above-described manner, and, in Step 800, signals representing the mixture $x_1[q_1]^*$, $x_2[q_2]^*$, ..., $x_e[q_e]^*$ based on the characteristic value vectors VX* are outputted to the color-material mixing apparatus 20, and the paint is produced by the color-material mixing apparatus 20, it is possible to fabricate a coated object such as a coated plate having a desired reflectance R*(α, λ).

Next, a description will be given of a second NNW method in accordance with the third embodiment. In the above-described first NNW method, although it is effective with respect to linear problems in which the convergence of solutions is readily obtained, there are cases where solutions do not converge in complicated problems such as nonlinear problems. This second NNW method is effective with respect to complicated problems such as nonlinear problems.

In the second NNW method, the characteristic value vector VX constituting the known reflectance R is set as an input to the network 74, and the reflectance vector VR corresponding to the known reflectance R is set as the teacher signal TC. The network 74 is converged (the system is stabilized) by using known relationships of L sets in the same way as described above. Consequently, it is possible to form the network 74 which outputs the reflectance VR when the characteristic value vector VX is given. This converged network 74 corresponds to the function f for solving a problem corresponding to Formula (22) above. Accordingly, in the second NNW method, to obtain the characteristic value vector VX* corresponding to a desired reflectance R*, an inverse function f^{-1} for obtaining a solution of an inverse problem corresponding to Formula (23) is determined, as will be described below.

It should be noted that, in the second NNW method, a network 74 in which the numbers of units in the respective layers are identical is used because a square matrix (details will be described later) is used. In this embodiment, a description will be given by citing an example in which the number of units of each layer is p (order is p). With respect to inputs and outputs to and from the network 74, there are cases where the number of elements of the characteristic value vector VX, i.e., an input, and the number of reflectance vectors VR, i.e., an output, do not agree. In that case, correspondence can be provided as a very small value whose resultant error will not affect in the process of propagation to a next layer is inputted as an input signal to the units of the input layer 78 whose number has exceeded the number of elements of the characteristic value vector VX inputted.

First, a v-th unit in the S layer and a u-th unit in the [S + 1] layer will be considered (see Fig. 18). If it is assumed that an input of the u-th unit in the [S + 1] layer is in_{S+1} (u), and that an output thereof is out_{S+1} (u), inputs from all the

units of the S layer are provided to the u-th unit in the [S + 1] layer, so that the relation between the input and output in the u-th unit in the [S + 1] layer can be expressed by Formula (31) below.

It should be noted that, in this embodiment, the order S_z of all final units in the respective layers is p, and $1 \leq v \leq p$, $1 \leq u \leq p$. Furthermore, since only one input signal corresponding to each unit is inputted to the input layer 78, it is assumed that $in_1(v) = out_1(v)$.

$$in_{S+1}(u) = \sum_{v=1}^{p} \{w_S(u, v) \cdot out_S(v)\} + t_{S+1}(u) \tag{31}$$

If this Formula (31) is developed, we have

$$\begin{aligned}
in_{S+1}(1) &= w_S(1, 1) \cdot out_S(1) + \ldots + w_S(1, p) \cdot out_S(p) + t_{S+1}(1) \\
in_{S+1}(2) &= w_S(2, 1) \cdot out_S(1) + \ldots + w_S(2, p) \cdot out_S(p) + t_{S+1}(2) \\
in_{S+1}(3) &= w_S(3, 1) \cdot out_S(1) + \ldots + w_S(3, p) \cdot out_S(p) + t_{S+1}(3) \\
&\vdots \\
in_{S+1}(p) &= w_S(p, 1) \cdot out_S(1) + \ldots + w_S(p, p) \cdot out_S(p) + t_{S+1}(p)
\end{aligned}$$

Here, a matrix IN_{S+1} and a matrix OUT_S are set as follows:

$$IN_{S+1} = [in_{S+1}(l), in_{S+1}(2), \ldots, in_{S+1}(p)]$$

$$OUT_S = [out_S(1), out_S(2), \ldots, out_S(p)]$$

$$T_{S+1} = [t_{S+1}(1), t_{S+1}(2), \ldots, t_{S+1}(p)]$$

and if a square matrix A_S in which the coupling coefficient $w_S(u, v)$ is set as an element is defined, Formula (31) above can be expressed by the following Formula (32):

$$IN_{S+1} = A_S \cdot OUT_S + T_{S+1} \tag{32}$$

where,

$$A_S = \begin{bmatrix} w_S(1, 1) & w_S(1, 1) & \ldots & w_S(1, p) \\ w_S(2, 1) & w_S(2, 2) & \ldots & w_S(2, p) \\ \vdots & \vdots & & \vdots \\ w_S(p, 1) & w_S(p, 2) & \ldots & w_S(p, p) \end{bmatrix}.$$

By using a sigmoid function with respect to this matrix OUT_S in the same manner as in Formula (25) above, Formula (33) below is defined. Accordingly, an inverse function of the sigmoid function expressed by the following Formula (33) is transformed into Formula (34), so that the relation between the input and output in the [S + 1] layer can be expressed by Formula (35) below.

$$OUT_S = \mathrm{sigmoid}(\mu_0, IN_S) = g(IN_S) \tag{33}$$

$$g^{-1}(X) = -\frac{\mu_0}{2} \ell n\left(\frac{1}{x} - 1\right) \tag{34}$$

$$IN_{S+1} = g^{-1}(OUT_{S+1}) \tag{35}$$

where, $g^{-1}(OUT_{S+1})$ is defined as follows:

$$\begin{bmatrix} (OUT_1) \\ (OUT_2) \\ (OUT_3) \\ \cdot \\ \vdots \\ (OUT_p) \end{bmatrix} \overset{\text{def.}}{=} g\left(\begin{bmatrix} g(OUT_1) \\ g(OUT_2) \\ g(OUT_3) \\ \cdot \\ \vdots \\ g(OUT_p) \end{bmatrix} \right)$$

Then, the following Formulae (36) can be derived by using Formulae (32) and (35) above:

$$OUT_1 = IN_1, \tag{36}$$

$$OUT_S = A_S^{-1} \cdot IN_{S+1} = A_S^{-1} \cdot g^{-1}(OUT_{S+1} - T_{S+1})$$

$$OUT_1 = A_1^{-1} \cdot g^{-1}(OUT_2) = A_1^{-1} g^{-1}(A_2^{-1} g^{-1}(\ldots A_{N-1}^{-1}(g^{-1}(OUT_N) - T_N)\ldots)$$

where S = 1, 2, ..., N - 1 As can be appreciated from Formulae (36) above, if an output signal from an output layer is obtained, it is possible to obtain an input signal to an input layer. Hence, Formulae (36) corresponds to the inverse function f^{-1}, which can be expressed by the following Formula (37):

$$f^{-1}(OUT_N) = A_1^{-1} g^{-1}(A_2^{-1} g^{-1}(\ldots A_{N-1}^{-1}(g^{-1}(OUT_N) - T_N)\ldots) \tag{37}$$

Since the inverse function f^{-1} can be determined in this way, it is possible to perform calculation for obtaining a characteristic value vector VX* corresponding to a desired reflectance R* by using the coupling coefficient of the converged network 74.

Next, a description will be given of the operation of this embodiment using the second NNW method. When a main routine for reproducing a coated color is executed (see Fig. 44), normalized values are set (Step 500), and processing for leaning the network 74 is conducted (Step 502). In the processing for learning the network 74 by the second NNW method, a learning processing routine shown in Fig. 67 is executed.

In Step 502A in Fig. 42, convergence processing of the network 74 (stabilization of the system) is carried out by using normalized values, as described above. In an ensuing Step 504A, a derivative is determined by using the coupling coefficient of the stabilized system. Namely, the square matrix A_S and a function g are determined. In an ensuing Step 506A, a square inverse matrix A_S^{-1} and an inverse function g^{-1} are derived from the square matrix A_S and the function g thus determined. In an ensuing Step 508A, the square inverse matrix A_S^{-1} and the inverse function g^{-1} thus determined are stored.

When the process of learning the network 74 is completed in this manner, the operation proceeds to Step 600 in Fig. 19 to read a new reflectance $R^*(\alpha, \lambda)$ desired by the designer or the like. In an ensuing Step 702, an output $x_1[q_1]^*$,

$x_2[q_2]^*$, ..., $x_e[q_e]^*$ of the network 74 with respect to the desired reflectance data R_{11}^*, R_{12}^*, ..., R_{nm}^* is obtained by using the square inverse matrix A_S^{-1} and the inverse function g^{-1} stored. If the characteristic value vector VX* for obtaining the new reflectance $R^*(\alpha, \lambda)$ is found in the above-described manner, and signals representing the mixture $x_1[q_1]^*$, $x_2[q_2]^*$, ..., $x_e[q_e]^*$ based on the characteristic value vectors VX* are outputted to the color-material mixing apparatus 20 (Step 800), and the paint is produced by the color-material mixing apparatus 20, it is possible to fabricate a coated object such as a coated plate having a desired reflectance $R^*(\alpha, \lambda)$.

Next, a description will be given of a third NNW method in accordance with the third embodiment. In the third NNW method, in the same way as in the second NNW method, the characteristic value vector VX constituting the known reflectance R is set as an input to the network 74, and the reflectance vector VR corresponding to the known reflectance R is set as the teacher signal TC. The network 74 is converged (the system is stabilized) by using known relationships of L sets in the same way as described above. Consequently, it is possible to form the network 74 which outputs the reflectance VR when the characteristic value vector VX is given.

Next, a description will be given of the operation of this embodiment using the third NNW method. When a main routine for reproducing a coated color is executed (see Fig. 44), normalized values are set (Step 500), and processing for leaning the network 74 is conducted (Step 502). In the processing for learning the network 74 by the third NNW method, a learning processing routine shown in Fig. 43 is executed.

In Step 502B in Fig. 43, convergence processing of the network 74 (stabilization of the system) is carried out by using normalized values (samples), as described above. In an ensuing Step 504B, as for the samples used in Step 502 above, the respective quantities of component materials are divided by a predetermined number of boundary values with respect to intervals where the values of the characteristic value vector VX are close, so as to set a predetermined number of interpolation characteristic value vectors VVX at equal intervals. In an ensuing Step 506B, interpolation reflectance vectors VVR, which are an output, are determined by using as an input the interpolation characteristic value vectors VVX set in Step 504B by using the aforementioned stabilized system. In an ensuing Step 508B, the correspondence between the characteristic value vectors VX and the reflectance vectors VR, which was used in the stabilization of the system, as well as the correspondence between the interpolation characteristic value vectors VVX and the interpolation reflectance vectors VVR, which was determined in Step 506B, are stored.

When the process of learning the network 74 is thus completed, the operation proceeds to Step 600 in Fig. 44 to read a new reflectance $R^*(\alpha, \lambda)$ desired by the designer or the like. In an ensuing Step 702, a reflectance vector VR or an interpolation reflectance vector VVR, which coincides with or is closest to the reflectance data R_{11}^*, R_{12}^*, ..., R_{nm}^* corresponding to the new reflectance $R^*(\alpha, \lambda)$ thus read, is selected. The characteristic value vector VX or the interpolation characteristic value vector VVX corresponding to the selected vector is set as an output $x_1[q_1]^*$, $x_2[q_2]^*$, ..., $x_e[q_e]^*$. If the characteristic value vector VX* for obtaining the new reflectance $R^*(\alpha, \lambda)$ is found in the above-described manner, and signals representing the mixture $x_1[q_1]^*$, $x_2[q_2]^*$, ..., $x_e[q_e]^*$ based on the characteristic value vectors VX* are outputted to the color-material mixing apparatus 20 (Step 800), and the paint is produced by the color-material mixing apparatus 20, it is possible to fabricate a coated object such as a coated plate having a desired reflectance $R^*(\alpha, \lambda)$.

Through the above-described first and second embodiments, two methods have been shown for obtaining an unknown characteristic value vector VX*. The first method in accordance with the first embodiment makes it possible to obtain high-precision solutions, but the amount of prior calculation is large. The second method in accordance with the third embodiment affords lower accuracy as compared to the first method, but the amount of calculation is small, and high speed processing is possible. As such, it suffices if the two methods are selectively used depending on applications.

Next, a description will be given of a fourth embodiment. In the above-described embodiments, after the reflectance $R(\alpha, \lambda)$ is set, a characteristic value vector VX for realizing the same is determined. Incidentally, designers in general are unfamiliar with numerical reflectances when seen from the standpoint of the designers, and in terms of the operating efficiency it is not appropriate for the reflectances per se to be set as objects of control. In this embodiment, therefore, a coating color is reproduced on the basis of the sense of the user such as the designer (hereafter referred to as the design sense). Since the fourth embodiment is arranged in a manner similar to those of the above-described embodiments, identical portions will be denoted by the same reference numerals, and a detailed description thereof will be omitted.

In addition, in this embodiment, a description will be given of a case where a coating color is selected on the basis of the Munsell color system and the CIE chromaticity coordinates which, when used ordinarily, are easy for color designers and personnel of paint manufacturers to understand.

Reflectances $R(\alpha, \lambda, VX_1)$, $R(\alpha, \lambda, VX_2)$, ..., $R(\alpha, \lambda, VX_L)$ are determined with respect to the above-described characteristic value vectors VX_1, VX_2, ..., VX_L. If these reflectances R are determined, the tristimulus values (X, Y, Z) and chromaticity (x, y) can be calculated from Formulae (38) and (39) below.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \frac{1}{k} \int R(\alpha, \lambda, VX) \cdot I(\lambda) \begin{pmatrix} \bar{x}(\lambda) \\ \bar{y}(\lambda) \\ \bar{z}(\lambda) \end{pmatrix} d\lambda \qquad (38)$$

where $k = 100 \cdot \int\{I(\lambda)\bar{y}(\lambda)d\lambda\}$,

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$: CIE color matching function,
λ: wavelength

This Y shows the brightness of the light $I(\lambda)$, and the color can be specified by plotting points on a chromaticity diagram of an orthogonal coordinate system in which values of x and y obtained from the following Formulae (39) are set as chromaticity coordinates, and x is plotted as the abscissa and y as the ordinate in a conventionally known manner (all the colors are included within a slanted bell shape:

$$x = X/(X + Y + Z) \qquad (39)$$

$$y = Y/(X + Y + Z)$$

In addition, since correspondences can be obtained between the chromaticity coordinates (x, y) and the Munsell color system through a table of JIS Z 8721 (Specification of Colors According to their Three Attributes) and the like, if the chromaticity coordinates (x, y) and the brightness Y are determined, it is possible to determine the three attributes of color in the Munsell system, i.e., hue (H), brightness (V), and chroma (C), corresponding thereto.

Accordingly, if the data on the sample coated plates obtained in the above-described embodiments are plotted at corresponding positions in the diagram of the Munsell color system shown in Fig. 21 or on the CIE chromaticity coordinates shown in Fig. 22, then all the plotted points have information on the reflectance $R(\alpha, \lambda)$. Incidentally, it is possible to use a diagram in which the Munsell color system and the CIE chromaticity coordinate system are made to correspond to each other, as shown in Fig. 23.

Next, a description will be given of the operation of this embodiment. When the operation proceeds to Step 600 in the aforementioned flowchart, a coating-color selection routine shown in Fig. 20 is executed. In Step 610 in Fig. 20, a command signal instructed via the keyboard 10 is discriminated so as to determine whether or not the colorimetric system instructed by the designer concerning the coating color is the Munsell color system. If YES is the answer in the determination, in Step 614, data on the Munsell color system stored in advance are read, and the diagram of the Munsell color system is displayed on the CRT 14, and the operation proceeds to Step 616. Meanwhile, if NO is the answer in the determination, in Step 612, data on the CIE XYZ colorimetric system stored in advance are read, and x-y chromaticity coordinates of the CIE XYZ colorimetric system are displayed.

In Step 616, a desired coating color is instructed by the designer or the like by selecting a point 86 plotted on the diagram of the Munsell color system or the CIE chromaticity coordinates. In an ensuing Step 618, the reflectance $R^*(\alpha, \lambda)$ is determined on the basis of the plotted point 86 thus selected, and this reflectance $R^*(\alpha, \lambda)$ is outputted. Accordingly, the characteristic value vector VX corresponding to this reflectance $R^*(\alpha, \lambda)$ is determined, and the desired coating color can be obtained from the characteristic value vector VX.

In addition, in the case where the designer selects the plotted point 86, and when a point between a plotted point and a plotted point is selected, it is possible to determine a characteristic value vector corresponding to the selected plotted point through interpolation or the like. Specifically, it suffices if, after $R(\alpha, \lambda, VX)$ with respect to small changes of the characteristic value vector VX is determined from the relation shown in Formula (20-3) above, the chromaticity (x, y) is calculated from Formulae (38) and (39), and the point is plotted on the diagram of the Munsell color system or the CIE chromaticity coordinates (see Fig. 24).

Next, a description will be given of a fifth embodiment. In the fifth embodiment, a coating color instructed vaguely by the designer or the like through the use of a verbal expression such as "provide a reddish tinge" is reproduced appropriately. It should be noted that since the fifth embodiment is arranged in a manner similar to those of the above-described embodiments, identical portions will be denoted by the same reference numerals, and a detailed description thereof will be omitted. Additionally, in this embodiment, it is assumed that a plurality of plotted points 86, which are selectable from the CIE chromaticity coordinates, have been determined in Step 216 in the fourth embodiment (see Fig. 24).

A description will be given of the operation of this embodiment. When a plotted point 86 on the CIE chromaticity coordinates, which is estimated by the designer or the like as being a desired coating color, is selected in Step 616 in Fig. 20, the operation proceeds to Step 620 in Fig. 25. A description will be given by assuming that this plotted point 86

selected by the designer or the like is a plotted point #P(x_p, y_p) on the x-y chromaticity coordinates.

In Step 620, a number of principal reference colors which allow the designer or the like to instruct tones are set on the x-y chromaticity coordinates. In this embodiment, as shown in Fig. 28, a plotted point #R specifying red, a plotted point #B specifying blue, and a plotted point #G specifying green, which are used as the so-called three primary colors, are set as the reference colors.

Fig. 26 shows color characteristics of main coating colors for an outer panel which are used in coating for vehicles. Each point in the drawing represents chromaticity of each coating color. Accordingly, since a rough area of regions of the colors to be controlled can be estimated, as for the predetermined reference colors mentioned above, it suffices if outermost plotted points are selected in such a way as to include this rough area.

Fig. 27 shows a color area 87 which can be reproduced in color printing. This color area 87 is an area surrounded by reference colors R, G, B, C, M, Y, and BK. These reference colors are plotted as colors based on tristimulus values shown in Table 2 below. The colors shown in this Table 2 may be stored in advance as the reference colors. Generally speaking, the CRT 14 has a slightly larger monitor gamut (the range of color reproduction) 88 than the color area 87. This being the case, however, considering the fact that control results are outputted and evaluated not only on the CRT but also in the form of color hard copies, it is desirable to consider the color area within this range.

Table 2

	x	y	z
G (green)	0.1790	0.4874	15.63
Y (yellow)	0.4323	0.4995	74.03
R (red)	0.6203	0.3395	14.78
M (magenta)	0.4808	0.2382	16.09
B (blue)	0.2281	0.1239	2.97
C (cyan)	0.1550	0.1977	18.92
W (white)	0.3135	0.3204	85.57
BK (black)	0.3410	0.2872	2.51

In an ensuing Step 622, the plotted point #P(x_p, y_p) selected by the designer or the like is read as a first presented color. In an ensuing Step 624, the instruction of a tone for causing the tone to be reflected on the plotted point #P is read. As for the instruction of the tone, a command corresponding to the designer's verbal expression, such as "provide a reddish tinge," to the coated color at the plotted point #P is entered through the keyboard 10.

The phrase "provide a reddish tinge" may be interpreted such that, in terms of the coordinate values on the x-y chromaticity coordinates with respect to the coating color, chromaticity changes from the plotted point #P toward the plotted point #R of the reference color (red). Accordingly, in an ensuing Step 626, a segment 90 connecting the plotted point #P and the plotted point #R is determined. At the same time, the plotted points located in the vicinity of the segment 90 are consecutively read as tendency points #P_{R1}, #P_{R2}, ..., starting with the plotted point #P, and the operation proceeds to Step 628. In Step 628, of these tendency points thus read, a tendency point which is closest to the presently instructed point (plotted point #P in this case) and is present in the direction of the tone (in the direction toward the plotted point #R) is selected. In an ensuing Step 630, a determination is made by an instruction by the designer or the like as to whether or not the degree of the tone is desired, and if the degree of the tone is at the desired coordinate position, the operation proceeds to Step 632.

Accordingly, the plotted points located in the vicinity of this segment 90 are repeatedly selected until the tone is reflected consecutively from the plotted point #P to the plotted point #R. As a result, in the case of "provide a reddish tinge," for instance, the plotted points are traced in the order of #P → #P_{R1} → #P_{R2}, ... as shown in Fig. 28, and the plotted point #P increases its reddish tinge in that order.

In an ensuing Step 632, a determination is made as to whether or not the provision of the desired tone has been completed for all the relevant colors. In other words, a determination is made as to whether or not the above processing has been completed with respect to the other colors such as blue and green. In this case, there are instances where a single-color tone is provided as in the above-described case, and instances where a tone is provided with respect to a plurality of colors. When a tone is provided to the plurality of colors, it suffices if the segment 90 is determined in Step 626 by assuming that the plotted point at the time when the tone of a predetermined color was determined is the presented color.

When the reflection of the tone is completed with respect to the plotted point #P concerning the initial presented color (original color), in Step 634, the chromaticity coordinate values of the determined plotted point are stored, and this routine ends.

Accordingly, as the reflectance $R^*(\alpha, \lambda)$ determined on the basis of the selected plotted point 86 is outputted (Step 618 in Fig. 45), the characteristic value vector VX corresponding to this reflectance $R^*(\alpha, \lambda)$ is determined, so that a coating color on which a desired tone is reflected can be obtained from the characteristic value vector VX. Therefore, it is possible to generate a desired coating color in a method easily understandable manner in tune with the sense of the designer.

Here, when coated surfaces are expressed, there are cases where a material texture is used in conjunction with the coating color. There are many phrases which express the types of material of the coated surfaces, and are typically classified into four types as shown in [States of Material] below. These states of material are important factors in determining the qualities of the coated surfaces.

[States of Material]

(1) Basic material texture: a mica texture, a metallic texture, and a solid texture
(2) Diffuse reflection: a flip-flop texture (a term expressing the difference between a light place and a dark place)
(3) Mirror reflection: a glossy texture and a lustrous texture
(4) Others: a texture of depth and a transparent texture

Accordingly, in the embodiments that follow, a coating color which is affected by the type of material on the basis of the design sense is reproduced. Since these embodiments are arranged in a manner similar to those of the above-described embodiments, identical portions will be denoted by the same reference numerals, and a detailed description thereof will be omitted.

In an sixth embodiment, a coating color which is affected by the basic material texture that is expressed sensuously as the mica texture, the metallic texture, and the solid texture is reproduced. In this embodiment, a metallic material x_{met} and a mica material x_{mic} are further added to the characteristic value vector $VX = (x_1, x_2, \ldots, x_e)$ for determining a coating color used in the above-described embodiments, and a new characteristic value vector VeX shown in the following Formula (40) is defined.

$$VeX = (x_1[q_1], x_2[q_2], \ldots, x_e[q_e], x_{met}[q_{met}], x_{mic}[q_{mic}]) \tag{40}$$

In this embodiment, a coating color affected by the basic material texture is reproduced, and, to simplify the description, it is assumed that the component materials and quantities thereof for reproducing the coating color itself have already been determined, and the composition and the like of a desired coated surface are calculated which can be formed by varying a quantity q_{met} of the metallic material x_{met} and a quantity q_{mic} of the mica material x_{mic} in a state in which the quantities q_i of the component materials $x_1, x_2, \ldots, x_e$ determining the coating color are fixed.

When an unillustrated power switch of the color reproducing apparatus is turned on, and the main routine (see Fig. 9) for reproducing a coating color is executed, normalized values are set (Step 500). Specifically, the operation proceeds to Step 540 shown in Fig. 54 to determine the characteristic value vector VeX to which the metallic material x_{met} and the mica material x_{mic} are added, by using the characteristic value vector VX based on the component materials x_i such as color materials used in the color-material mixing apparatus 20.

In an ensuing Step 542, in the same way as in the first embodiment, the metallic quantity q_{met} is appropriately divided into [P + 1] parts by a boundary value q_{metB} $(1 \le B \le P)$ and the quantity of mica q_{mic} by a boundary value q_{micC} $(1 \le C \le P)$. As a result, the metallic material x_{met} and the mica material x_{mic} are developed into P quantities in which their quantities increase or decrease in stages.

It should be noted that a setting is provided such that the sum of the metallic quantity q_{met} and the quantity of mica q_{mic} becomes a fixed quantity as shown in the following Formula (41):

$$q_{metB} + q_{micC} = \rho \text{ (constant)} \tag{41}$$

$\rho = q_{met1} > q_{met2} > \cdots > q_{metp} = 0$

Accordingly, the number of combinations of the characteristic value vectors VeX due to these quantities q_{metB} and q_{micC} becomes P^2.

In an ensuing Step 544, each of the P^2 characteristic value vectors VeX_h $(h = 1, 2, \ldots, P^2)$ is determined. Namely, each characteristic value vector VeX_h at a time when the respective quantities of the metallic material x_{met} and the mica material x_{mic} are consecutively varied is determined.

In an ensuing Step 546, a paint is produced which is obtained by mixing the color materials and the like on the basis

of the quantities of the components materials of the characteristic value vectors VeX_h determined. The reflectance $R_h(\alpha, \lambda, VeX_h)$ of the coated surface of a plate coated with the produced paint is determined by actual measurement. Accordingly, P^2 samples can be generated as shown in Table 3 below.

Table 3

No.	Metallic Material	Mica Material	Reflectance	Material Texture
1	$\rho = q_{met1}$	$q_{mic1} = 0$	$R_1(\alpha, \lambda, VeX_1)$	metallic
2	q_{met2}	q_{mic2}	$R_2(\alpha, \lambda, VeX_2)$	↑
⋮	⋮	⋮	⋮	↓
P^2	$0 = q_{metp}$	$q_{micp} = \rho$	$R_{p2}(\alpha, \lambda, VeX_{p2})$	mica

Table 3 above shows that a higher-ranking mixture (the smaller the number) gives a stronger metallic texture, and a lower-ranking mixture (the larger the number) gives a stronger mica texture.

Furthermore, as already described in the third embodiment, if more detailed relations of correspondence are determined by interpolation on the basis of the relations of the aforementioned P^2 samples, it is possible to select a more detailed metallic texture and mica texture.

When the processing of setting normalized values is thus completed, the new reflectance $R^*(\alpha, \lambda)$ desired by the designer or the like is read (Step 600 in Fig. 34), and a new characteristic value vector VeX^* $(x_1^*, x_2^*, ..., x_e^*, x_{met}, x_{mic})$ with respect to the new reflectance $R^*(\alpha, \lambda)$, i.e., the quantities of component materials such as metallic material and mica, are calculated (Step 700 in Fig. 9). Consequently, signals representing the characteristic value vector VX^* (mixture) are outputted to the color-material mixing apparatus 20 (Step 800 in Fig. 9), and the paint is produced by the color-material mixing apparatus 20, thereby making it possible to fabricate a coated object such as a coated plate having a desired reflectance $R^*(\alpha, \lambda)$.

A description will be given of the division of the quantities of the specific metallic material x_{met} and mica material x_{mic} by using the component materials of the already existing coating color A used in the second embodiment. It should be noted that when the quantities of metallic material x_{met}, the mica material x_{mic}, and all the component materials determining the color are set as a quantity $q = q_1 + q_2 + ... + q_e$, the quantity q is fixed. This quantity q becomes 32.93 g, as shown below.

$$q = \underset{\text{(tinting black)}}{11.70} + \underset{\text{(blue black)}}{6.69} + \underset{\text{(indanthrene blue)}}{14.54} = 32.93\ (g)$$

Meanwhile, the quantities q_{met}, q_{mic} are divided appropriately. Here, they are varied in the order of 0, 10, ..., 50 (g), respectively. As a result, a total of $6^2 = 36$ samples can be produced, as shown in [State C] below.

[State C]

$$(q_{met}, q_{mic}) = (0, 0),$$
$$= (0, 10),$$
$$= (0, 20),$$
$$= (50, 50)$$

Although, in the above, a coating color based on the basic material texture is reproduced by allowing the metallic texture and the mica texture to be reflected, it is also possible to reproduce a coating color which is affected by the basic material texture which sensuously expresses the mica texture, metallic texture, and solid texture. Namely, the solid texture is included in the above-described material texture.

In this case, as shown in Fig. 30, it suffices if the case is considered in a three-dimensional space of a coordinate system in which the quantity q of all the component materials determining the coating color, the metallic quantity q_{met}, and the mica quantity q_{mic} are set as axes.

Next, the following formulae are used instead of Formula (41) above.

$$q = q_1 + q_2 + \dots + q_e$$

$$q + q_{metB} + q_{micC} = \rho \text{ (constant)}$$

$$q \geq 0,\ q_{metB} \geq 0,\ q_{micC} \geq 0$$

Since the quantities q, q_{met}, and q_{mic} correspond to the solid texture, metallic texture, and mica texture, respectively, as shown in Fig. 30 , if a point P(x, y, z) on a triangle (see Fig. 56) having a point A(ρ, 0, 0), a point B(0, ρ, 0), and a point C(0, 0, ρ) as apexes is moved, it is possible to control the solid texture, the metallic texture, and the mica texture while allowing them to be interrelated to each other. In this case, it suffices if this triangle is divided appropriately, the points are present in such a manner as to be dispersed at appropriate positions on the triangle, and samples concerning the respective points are produced.

It should be noted that, although, in the sixth embodiment, samples are produced in the processing of setting normalized values, the metallic quantity q_{met} and the mica quantity q_{mic} may be determined after the respective quantities of the component materials determining the coating color are determined. In this case, it suffices if the aforementioned triangle (see Fig. 31) is displayed on the CRT 14 to allow desired positional coordinates to be inputted.

Next, a description will be given of a seventh embodiment. In the seventh embodiment, a coating color which is affected by diffuse reflection which is sensuously expressed as flip-flop texture is reproduced. This flip-flop texture is sometimes expressed as the modulation of light and darkness, and is conceivably dependent mainly upon the varied-angle characteristic (a change in the reflectance or brightness Y due to the varied angle). Accordingly, in this embodiment, the characteristic value vector VeX which includes the metallic material x_{met} and the mica material x_{mic}, which are bright materials, are used (see Formula (40)).

Next, a description will be given of the operation of this embodiment. When an unillustrated power switch of the color reproducing apparatus is turned on, a main routine (see Fig. 57) for reproducing a coating color is executed, and normalized values are set (Step 500). Then, a new reflectance $R^*(\alpha, \lambda)$ desired by the designer or the like is read (Step 600), and a new characteristic value vector VX^* (quantities of the component materials) corresponding to this new reflectance $R^*(\alpha, \lambda)$ is computed (Step 700). In an ensuing Step 704, the characteristic value vector VeX on which the flip-flop texture is reflected is determined, and a signal representing this characteristic value vector VeX is outputted to the color-material mixing apparatus 20 (Step 800). The paint is produced at a mixing ratio based on the characteristic value vectors by the color-material mixing apparatus 20, so that it is possible to fabricate a coated object such as a coated plate having a desired reflectance (coated color) on which the flip-flop texture has been reflected.

In Step 704 above, the flip-flop processing routine shown in Fig. 60 is executed. The reflectance $R(\alpha, \lambda)$ of the coated surface is approximated from discrete points with respect to wavelengths based on unit vectors VR_1(VeX), VR_2(VeX), ..., VR_n(VeX). Accordingly, in Step 722 in Fig. 60, the unit vectors VR_j are read. In an ensuing Step 724, a curve $LR_1(VeX, \lambda)$, $LR_2(VeX_1, \lambda)$, ..., $LR_n(VeX, \lambda)$ in which the discrete points of these unit vectors VR_j are connected by interpolation, as shown in Fig. 33, is determined. If the characteristic of a predetermined wavelength band is thus determined, the brightness Y_j is determined from Formula (42) below, so that the brightness for each varied angle α is determined.

$$Y_j = \frac{1}{k} \int_{\lambda} LR_j(\alpha, \lambda, VeX) \cdot I(\lambda) \cdot \bar{y}(\lambda)\, d\lambda \tag{42}$$

where $k = 100 \cdot \int \{I(\lambda)\bar{y}(\lambda)d\lambda\}$,

$\bar{y}(\lambda)$: CIE color mating function
$I(\lambda)$: spectral distribution of the light source

In an ensuing Step 728, the varied-angle characteristic obtained from the brightness Y_j determined in Step 726 is rendered on the CRT 14. Namely, since the brightness Y_j represents brightness for each varied angle, if points plotted on the coordinate plane with the varied angle α as the abscissa and the brightness Y_j as the ordinate are connected by a free curve by means of interpolation, it is possible to render the brightness in the direction of the varied angle, i.e., the varied-angle characteristic.

Fig. 34 shows characteristic curves ① and ② of different varied-angle characteristics. As can be appreciated from the drawing, the characteristic curve ② shows a marked difference between light and darkness as compared to the characteristic curve ①, and therefore gives a more pronounced flip-flop texture.

In an ensuing Step 730, the reflectance $R(\alpha, \lambda)$, in which the quantities of predetermined or appropriate component materials among the component materials of the characteristic value vectors VeX are varied by small amounts, is determined. In an ensuing Step 732, a determination is made as to whether or not the above processing has been completed a predetermined number of times (e.g., five times), and the above processing is executed repeatedly. Consequently, a plurality of varied-angle characteristics are rendered. In an ensuing Step 734, the user such as the designer selects a characteristic curve having a desired degree of flip-flop texture by referring to the rendered characteristic curves, and this routine ends. Accordingly, since the characteristic value vector VeX corresponding to this characteristic curve is determined easily, it is possible to fabricate a coating color exhibiting desired flip-flop texture on the basis of the characteristic value vector VeX.

As described above, it is not easy to estimate virtual flip-flop texture even with the varied-angle characteristic curve rendered on the CRT 14 for obtaining a coating color having a desired flip-flop texture. Therefore, if the coating color having the selected degree of flip-flop texture is displayed as a shaded figure of a semicylindrical shape after the selection of the varied-angle characteristic curve, and if judgment or the like of a gradation due to the display of this shaded figure is provided, it is possible to impart a visual judgment.

In the above, a description has been given of a case where a coating color is formed in which desired flip-flop texture is obtained by selecting a curve of desired flip-flop texture from varied-angle characteristic curves rendered on the CRT 14; however, the present invention is not limited to the same. For instance, coated plates having a plurality of different degrees of flip-flop texture may be formed in advance as samples, and selection may be made therefrom. If a need is expressed by the designer or the like to cope with sensuous expressions such as "a color having a greater degree of flip-flop texture," it suffices if a plurality of varied-angle characteristic curves are determined in the above-described manner, and characteristic value vectors having greater degrees of flip-flop texture are selected consecutively.

Next, a description will be given of a eighth embodiment. In the eighth embodiment, a coating color which is affected by mirror reflection that is sensuously expressed as the glossy texture or lustrous texture is reproduced.

The glossy texture or lustrous texture is mainly dependent on the surface finish (polishing or the like), but is also dependent on the thickness (quantity) of a clear coat. It suffices if the normalized-value setting routine in Fig. 29 is executed by setting the clear coat material as a component material x_{ce} and by setting a quantity thereof as q_{ce} and substituting the clear coat material x_{met} for the metallic material x_{met} and the mica material x_{mic} in the above-described sixth embodiment. In this case, the quantity q_{ce} is divided into p parts as $q_{ce1} < q_{ce2} < ... < q_{cep}$, and reflectances thereof are determined. Accordingly, it is possible to produce P samples in the same way as in Table 3 above.

In a case where the quantity of the clear coat material x_{ce} is varied, the quantities of the color materials and bright materials are fixed, and only the quantity of the clear coat material is varied. Generally, it is preferable to divide the quantity of the clear coat material of 0 to MAX (maximum value, e.g., 100 g) into 30 to 50 parts so as to produce samples. In addition, in accordance with an interpolation method similar to those of the first and third embodiments, it is possible to obtain a more detailed lustrous texture on the basis of the relationships of the aforementioned P samples.

Next, a description will be given of an ninth embodiment. In the ninth embodiment, a coating color which is affected by the states of material other than those mentioned above and which are expressed sensuously is reproduced. Senses felt by the designer and the like due to these other states of material mainly include a texture of depth. Such textures perceived by the designer or the like are related to reflectance characteristics and varied-angle characteristics. If relationships between such a texture and a reflectance can be known, the characteristic value vector is determined, so that

it is possible to reproduce a coating color having a texture of depth. A detailed description will be given of a process for handing this texture of depth quantitatively.

The texture of depth is a sensuous expression used by a person who perceives an object surface. This texture of depth can be broadly classified into a texture of depth A which appears as if the object surface has a geometrically three-dimensional depth, a texture of depth B which appears as if the object surface has a virtually three-dimensional depth, and a texture of depth C which makes the viewer to associate it with high-grade qualities, such as by imparting him a sense of magnificence, a sense of splendid style, and a sense of awe. These textures, i.e., the texture of geometric depth A, the texture of virtual depth B, and the texture of depth C imparting high-grade qualities are mainly related to hue and material texture. The material texture referred to here is mainly due to the bright material. In an extreme case, one does not sense a depth in a chromium-plated surface. As a reason for this, it can be conjectured that since the chromium-plated layer gives only mirror reflection, the chromium-plated layer does not transmit information about such as the internal structure and effect.

Accordingly, the texture of depth is conceivably attributable to propagation of reflected light due to the internal structure of the object surface when visually observed. The form of reflection of this reflected light, if broadly classified, includes mirror reflection and diffuse reflection, as is known.

The mirror reflection is unrelated to the type of coated surface, and substantially conforms to Fresnel reflection. Fig. 36 shows, as experimental examples, a reflectance curve 62A of Metallic Color A4245 (gold), a reflectance curve 62B of Solid Color 3E5 (red), and an ideal reflectance curve 62C determined by computation on the basis of Fresnel's formula shown in Formula (43) below. Thus, it can be seen that, as a physical amount for expressing a texture of depth, mirror reflection is unrelated, and only diffuse reflection is involved. This diffuse reflection can be determined by measurement by the aforementioned gonio-spectrophotometer 24.

$$f = \frac{1}{2}\left\{\left[\frac{n_2\cos\theta_2 - n_1\cos\theta_1}{n_2\cos\theta_2 + n_1\cos\theta_1}\right]^2 + \left[\frac{\cos\theta_2/n_2 - \cos\theta_1/n_1}{\cos\theta_2/n_2 + \cos\theta_1/n_1}\right]^2\right\} \tag{43}$$

where

- f: Fresnel's reflectance (an intermediate value between an S-wave and a P-wave)
- n_1: refractive index of air $\cong$ 1.00
- n_2: refractive index of a medium (1.567 in this embodiment)
- θ_1: incident angle
- θ_2: reflection angle

$$n_1/n_2 = \sin\theta_1/\sin\theta_2 \text{ (Snell's law)}$$

Next, with respect to this texture of depth, a description will be given of the texture of depth B and the texture of depth C. First, a case is considered in which the coating color is uniform. There are cases where portions of a coated surface having an identical hue differ in the texture of depth. Since this difference in the texture of depth is considered to correspond to the difference in brightness due to the varied angle, the difference in the texture of depth can be expressed by the difference in the varied-angle characteristic (see Fig. 33).

Accordingly, an experiment, which is described below, was conducted to determine the conditions of the texture of depth with respect to a coated plate whose coating color was uniform. As an experimental object, a coated plate which had a texture of depth was prepared, and the coated plate was formed in a semicircular shape to permit the varied-angle characteristic of the coated plate to be measured univalently, as shown in Fig. 37B. Reflectances at a plurality of positions a, b, c, and d on the coated surface of this semicircular coated plate were measured. The position a was a highlight position of this coated plate, while positions b, c, and d were offset by predetermined varied angles, respectively, from the position a in a predetermined direction. On the basis of these measured reflectances, brightness Y_j was calculated by using Formula (42) so as to determine the varied-angle characteristic (see Fig. 37 A). At a position in the vicinity of the positions a and b, i.e., near the highlight (at a portion where the light and shade varied from the highlight a to b and c), a change in brightness became intense. Through this experiment, it was found that if the coated plate was viewed with an area at these positions a and b masked, the sense of the texture of depth was not felt at the positions c and d where the change in brightness was relatively flat. Consequently, it can be assumed that the sense of the texture of depth is felt in the vicinity of a highlight (at the portion where the light and shade varies from the highlight a to b and c).

Fig. 38 shows characteristics 39 A, 39 B, 39 C, and 39 D illustrating the relationship between the varied angle and brightness when the above-described experiment was conducted with respect to a plurality of coated plates. As can be appreciated from Fig. 38 , it was found that in a case where the varied-angle characteristic of varied angle $\alpha \geq 5°$ was

relatively small, and the change was slower, the sense of the texture of depth was more easily felt (characteristics 64A and 64B in Fig. 38). Meanwhile, the sense of the texture of depth was not felt in a case where the highlight (position a) shone brightly, the change in brightness between adjacent positions (between the positions a and b, and b and c, ...) was small, and the overall reflectance was high (characteristics 64C and 64D in Fig. 38). Accordingly, the following conditions (i) and (ii) of depth are set as the conditions of the texture of depth in a coated plate where the coating color is uniform:

(i) The brightness Y of an area with $\alpha \geq 5°$ excluding a highlight portion is not large.
(ii) The change in brightness of an area where the brightness Y is not large is slow.

From these conditions (i) and (ii), it can be estimated that the sense of the texture of "depth" is similar to the sense of "dark." However, it is not that the overall coated surface is uniformly dark, but a slow change in brightness is present there. This is similar to a situation in which one looks at the sun that appears vaguely in the form of streaks of light shining through layers of trees in a thicket of a dark forest, for instance. In this case, the sun may be compared to the highlight, and the light and shade of the trees in the forest to the brightness of the paint.

Next, a case will be considered where the coating color is varied by fixing the amounts of bright materials and the like determining material texture. Between bright colors and dark colors, the sense of the texture of depth is generally more easily felt in the case of the dark colors, as described above. Accordingly, if a paint consisting of color materials such as chromatic pigments is formed, and if the reflectance is determined at a varied angle (e.g., $\alpha = 40°$), excluding mirror reflection, with respect to a plate coated with this paint, it is possible to obtain correspondence between the coating color and the reflectance. For instance, reflectances R_0 of such colors as indigo, dark blue, and black are low, while reflectances R_0 of such colors as white and yellow are high. Accordingly, it can be understood that the condition of the texture of depth concerning color is the following condition of depth (iii):
(iii) The reflectance of a diffuse reflection portion is low.

Thus, conditions of depth specifying the texture of depth are set. To quantify these conditions of depth (i), (ii), and (iii), a value F_1 is defined by using the following Formula (44):

$$F_1 = m_1 f_1 \left[\iint_{\lambda\,\alpha} R(\alpha, \lambda, VeX) \cdot \bar{y}(\lambda)\, d\alpha d\lambda \right] \tag{44}$$

where

wavelength:	$380 \leq \alpha \leq 720$
varied angle:	$5° \leq \alpha \leq 90°$
m_1:	positive constant
$f_1(x)$:	decreasing function in a broad sense (when $x_1 < x_2$, $f_1(x_1) \geq f_1(x_2)$; hereafter referred to as the decreasing function)

This value F_1 becomes greater as the reflectance $R(\alpha, \lambda, VeX)$ becomes smaller, corresponding to an increase in the sense of the texture of depth.

Next, since a smooth continuous curve obtained by spline interpolation or the like by using the brightness Y_1, Y_2, ... for each varied angle as points in Formula (42) above is a function of the varied angle α, in this embodiment, the function $Y(\alpha)$ is defined as a function expressing the brightness Y with respect to the varied angle α. A differential value $dY(\alpha)/d\alpha$ in which this function $Y(\alpha)$ differentiated with respect to the varied angle α expresses the gradient of the function $Y(\alpha)$.

With respect to the varied angle α ranging from 5° to 90°, N angles $\alpha_1, \alpha_2, ..., \alpha_n$ ($5° \leq \alpha_1 < \alpha_2 < ... < \alpha_n = 90°$) are appropriately selected (e.g., 86 angles including 5°, 6°, ..., 89°, 90° in units of 1°). Differential values are determined with respect to each of the selected angles α_i by using Formula (45) below. Namely, the angle α_i can be determined freely, if measurement points (α_i, Y_i) are plotted on two-dimensional coordinates with the varied angle α and brightness Y set as axes, and if the function $Y(\alpha)$ which becomes a smooth curve is obtained such as by minimizing square errors with respect to measurement points through approximation processing by spline interpolation or the like. This smooth curve can be differentiated, so that the differential values $a_i = dY(\alpha)/d\alpha$ can be determined.

$$a_i = \frac{dY(\alpha)}{d\alpha} \Big|_{\alpha=\alpha_1} \tag{45}$$

By using the differential values a_1, a_2, ...; a_n thus determined, a dispersion αA^2 and a mean value μA are determined by the following Formulae (46) and (47):

$$\sigma_A{}^2 = \frac{1}{N}\sum_{i=1}^{N}(a_1 - \mu_A)^2 \tag{46}$$

$$\mu_A = \frac{1}{N}\sum_{i=1}^{N} a_i \tag{47}$$

Here, the fact that the change in brightness Y is slow means that the dispersion $\alpha_A{}^2$ is small, and that the absolute value $|\mu_A|$ of the mean value is small. Accordingly, the following amount shown in Formula (48) is defined.

$$F_2 = m_2 f_2(\sigma_A) + m_3 f_2(|\mu_A|) \tag{48}$$

where

m_2, m_3:	positive constants
$f_2(x)$, $f_3(x)$:	decreasing functions

Consequently, the greater the value F_1, the more the condition of depth (iii) is satisfied, and the more the texture of depth increases. In this way, the texture of virtual depth B and the texture of depth C appealing to the sense can be quantified.

Next, a description will be given of the texture of depth A. The fact that a person senses the presence of a geometrically three-dimensional depth in an object corresponds to the fact that that person perceives a perspective.

Fig. 39A shows an image without a perspective, while Fig. 64B shows an image in an accurate perspective.

Even if an accurate perspective is not provided as in Fig. 39A, it is possible to sense a texture of depth to a certain extent. For instance, when stars in the night sky are viewed, one will be able to feel a depth of the universe. The large moon appears to be closer than small stars. In addition, flickering stars may appear to be much closer, while bluish stars may be felt to be more distant than reddish stars.

When the case of a paint is considered, particles of a bright material are considered to correspond to the aforementioned stars. In the case of stars, experientially speaking, the greater the number of stars having different sizes, colors and, twinkling light, the more one will feel a depth. Accordingly, the more numerous the particle sizes, colors, and reflection characteristics the bright materials in the paint have, the more one will feel a depth.

For example, if a comparison is made between two paints containing bright materials having different particle-size distributions as shown in Figs. 65A and 65B, it can be said that the paint containing the bright material shown in Fig. 65B gives a greater sense of depth than the counterpart shown in Fig. 40A.

Accordingly, of bright materials xi, the number of bright materials having a particle size ξ (nm) is assumed to be $a\xi$. For instance, the following [Example] is known as the range of particle size:

[Example]

Micro titanium yellow:	0.03 µm
Silver plated glass flake:	10 to 40 µm
Aluminum solid-solution flake red iron oxide:	10 to 40 µm
Small-particle-size pearl:	15 µm or less

Thus, various bright materials and their particle sizes are known, but their particle size may be considered in the range of 0 to 50 µm. The particle-size distribution can be determined easily by image analysis techniques.

Next, the dispersion $\sigma_r{}^2$ of the particle-size distribution is determined as in Formula (46) above, and it is assumed that the greater the value of the dispersion $\sigma_r{}^2$, the greater the sense of the texture of depth. Furthermore, although the dispersion $\sigma_r{}^2$ is determined on the basis of the particle-size distribution, dispersions $\sigma_C{}^2$, $\sigma_R{}^2$ are also determined with respect to the variation of color and the variation of the reflectance characteristic, and a value F_3 weighted by appropriate positive real numbers m_4, m_5, and m_6 is defined as shown in the following Formula (49):

$$F_3 = m_4 f_4(\sigma_r{}^2) + m_5 f_5(\sigma_C{}^2) + m_6 f_6(\sigma_R{}^2) \tag{49}$$

The texture of depth A can be quantified by this value F_3. Consequently, if the depth index F is determined by using this value F_3 as well as the values F_1, F_2 determined above, as shown in Formula (50) below, then each of the texture of depth A, the texture of depth B, and the texture of depth C can be quantified.

$$F = F_1 + F_2 + F_3 \tag{50}$$

where

$f_4(x)$, $f_5(x)$, $f_6(x)$: increasing functions in a broad sense (if $x_1 < x_2$, then $f_i(x_1) \leq f_i(x_2)$ (i = 4, 5, 6)) It is assumed that the greater the depth index F, the greater the depth.

Here, $f_1(x)$, $f_2(x)$, ... are defined as in the following Formulae (51):

$$f_1(x) = f_2(x) = f_3(x) = l/x \tag{51}$$

$$f_4(x) = f_5(x) = f_6(x) = x$$

As a result, the depth index F can be expressed by Formula (52) shown below.

$$F = \frac{m_1}{f_1} + \frac{m_2}{\sigma_A} + \frac{m_3}{|\mu_A|} + m_4\sigma_r{}^2 + m_5\sigma_c{}^2 + m_6\sigma_R{}^2$$

where,

$$f_1 = \int_\lambda \int_{\alpha=25} R(\alpha, \lambda, VeX) \cdot \bar{y}(\lambda)\, d\alpha d\lambda$$

$$380 \leq \lambda \leq 720$$

In addition, as for the dispersion $\sigma_C{}^2$, a coating color based on a bright material is set as coordinate values $¢(L_1{}^*, a_1{}^*, b_1{}^*)$, $¢(L_2{}^*, a_2{}^*, b_2{}^*)$, ..., in an Lab colorimetric system, a reference coating color is set as coordinate values $¢_w((L_w{}^*, a_w{}^*, b_w{}^*)$, and coating colors $¢_1$, $¢_2$, ... are defined in terms of deviations

$$\xi_1 = |¢_w - ¢_1|,\ \xi_2 = |¢_w - ¢_2|,\ \ldots$$

with respect to white. Hereafter, the deviation ξ will be expressed as the coating color ξ. It is assumed that the number of bright materials used in a coating color ξ_i is a_i, and the dispersion $\sigma_C{}^2$ is determined in the same manner as in Formula (46).

It should be noted that, in this embodiment, white in which $L_w{}^* = 100$, $a_w{}^* = b_w{}^* = 0$ is used as a reference coating color $¢_w$. Also, the color of the bright material as a single substance can be measured by spectrophotometric colorimetry of the surface consisting of the bright material alone.

As for the dispersion $\sigma_R{}^2$, the brightness Y, which is calculated by using Formula (42) above from the reflectance when the varied angle of a coated surface made of a bright material i is 40°, is set as the brightness ξ_i. At this time, values expressing positions in a permutation in which brightness ξ_1, ξ_2, ... are rearranged in an ascending order are set as values n_1, n_2, ..., ($n_1 \leq n_2 \leq$ ...). If the number of bright materials having the brightness of the value n_i is α_i, the dispersion $\sigma_R{}^2$ can be determined in the same way as in Formula (46).

Next, a description will be given of the operation of this embodiment. The following description will be given by assuming that the reflectance of a coated surface with respect to a characteristic value vector VeX in which the coating color or material is fixed is R(α, λ, VeXi), and that the depth index with respect to this characteristic value vector VeX is F_i. To simplify the description that follows, correspondences are determined between reflectances and depth indexes by fixing chromatic pigments or the like and varying the quantities of bright materials.

In Step 560 in Fig. 41, characteristic value vectors VeX based on component materials x_i including the color materials and bright materials used in the color-material mixing apparatus 20 are determined.

In an ensuing Step 562, in the same way as in the above-described embodiments, the quantities of metallic material and the mica material are appropriately divided by a boundary value into [P + 1] parts. Consequently, each of the bright materials including the metallic material and mica material is developed into P quantities in which the component quantity increases or decreases in stages. Therefore, the combinations of the characteristic value vectors VeX based on these component quantities become P combinations.

In an ensuing Step 564, the respective P characteristic value vectors VeX_h ($h = 1, 2, ..., P$) are determined. In other words, each of the characteristic value vectors VeX_h when the quantities of the bright materials are consecutively varied is determined. In an ensuing Step 566, the depth index F described above is determined in correspondence with each of these characteristic value vectors VeX_h, and the depth indexes F are rearranged in order starting with a minimum value in an ensuing Step 568. As a result, characteristic value vectors of a plurality of coating colors having varying textures of depth are determined with respect to coating colors of an identical hue determined by these characteristic value vectors VeX_h.

In an ensuing Step 570, a paint is produced by mixing color materials and the like on the basis of the quantities of the component materials having the characteristic value vectors VeX_h thus determined. The reflectance $R_h(\alpha, \lambda, VeX_h)$ of a plate coated with the produced paint is determined by actual measurement. Accordingly, as shown in Table 4 below, P samples can be produced, and correspondences can be obtained between the reflectances and depth indexes by fixing the chromatic pigments and varying the bright materials. Incidentally, the depth indexes in Table 4 are such that $F_1 \leq F_2 \leq ... \leq F_p$.

Table 4

Characteristic Value	Reflectance	Depth Index	Texture of Depth
VeX_1	$R_1(\alpha, \lambda, VeX_1)$	F_1	small
VeX_2	$R_2(\alpha, \lambda, VeX_2)$	F_2	↕
⋮	⋮	⋮	
VeX_p	$R_p(\alpha, \lambda, VeX_p)$	F_p	large

As described above, in accordance with the foregoing embodiments, coating colors or materials can be generated virtually on the CRT and can be selected prior to manufacturing actual objects (objects of various configurations coated with paints or the like thereon). In addition, since it suffices if a characteristic value vector is derived for the first time when a desired coating color is generated (selected), and if an actual object is manufactured on the basis of the characteristic value vector thus derived, it is possible to substantially reduce the cost required for manufacturing the actual object.

Although, in the above, a description has been given of a case where a coated plate having an identical hue and different textures of depth is formed, the present invention is not limited to the same, and may be applied to cases when a coating color is selected. In this case, if the depth indexes F are determined as described above after the determination of a coating color, and if only coating colors having textures of depth are displayed in the ascending order of the depth index F, it is possible to select a coating color having a desired color and a desired texture of depth among the coating colors having the displayed textures of depth. Further, if a need is expressed by the designer or the like to cope with sensuous expressions such as "a color with a texture of greater depth," it suffices if the depth indexes F are determined in the above-described manner after the determination of a coating color, and characteristic value vectors having

greater depth indexes F are selected consecutively.

In a case where a finer indexing of the depth index is required to reproduce a subtle texture of depth, it suffices if relationships of correspondence are increased by interpolation referred to in the first and third embodiments.

In addition, a coating color may be reproduced as a color image by connecting to the color reproducing apparatus a color copying apparatus, which is based on a thermal transfer process, an ink-jet process, an electrophotographic process, a silver-halide photographic process, or the like for outputting color copy images using color data in the colorimetric system or the like as input values.

Claims

1. A method of selecting a coating color, comprising the steps of

   (a) determining a plurality of predetermined relationships of correspondence between characteristic values constituted by amounts of respective ones of all the component materials constituting a coated surface and a spectral reflectance distribution of the coated surface based on the characteristic values with respect to a predetermined coating color on said coated surface which is formed with one or a plurality of layers on an object to be coated and in which each of the layers is formed of at least one component material;
   (b) calculating by performing interpolation on the basis of said plurality of predetermined relationships of correspondence the spectral reflectance distributions of coating colors in which a quantity of at least one component material of all the component materials that are determined on the basis of said plurality of predetermined relationships of correspondence is varied;
   (c) selecting a spectral reflectance distribution corresponding to a coating color to be reproduced on the basis of the relationships of interpolated correspondence.

2. A method of selecting a coating color according to claim 1, wherein comprising the step (a) includes step of determining predetermined tristimulus values based on the spectral reflectance distribution of the coated surface corresponding to the characteristic values $\boxed{X}$, and the step (b) includes step of determining the tristimulus values based on the calculated spectral reflectance distributions of the coated surface; further comprising steps of

   (d) determining coordinate values on coordinates of a predetermined colorimetric system with respect to each of the predetermined tristimulus values and interpolated tristimulus values, and setting a plurality of coordinate values among the determined coordinate values as reference coordinate values for expressing reference colors; and
   (e) selecting the coating color by consecutively selecting coordinate values in a direction from coordinate values specifying an instructed color to the reference coordinate values, starting with proximate coordinate values.

3. A method of selecting a coating color, according to claim 1, further comprising steps of

   (f) on the basis of predetermined and calculated spectral reflectance distributions, determining varied-angle characteristics of the coated surface, which express flip-flop relationships between a varied angle and brightness at the varied angle, when a light-receiving angle is varied during reception of light reflected from the coated surface; and
   (g)selecting the coating color by selecting the varied-angle characteristic of the coating color to be reproduced from the determined varied-angle characteristics.

4. A method of selecting a coating color, according to claim 1, further comprising steps of

   (h)determining a particle-size distribution of each of the component materials for each of the characteristic values in the predetermined relationships of correspondence and the characteristic values in the interpolated relationships of correspondence, and determining depth indexes specifying the depth of coating colors on the basis of the spectral reflectance distributions in the predetermined relationships of correspondence or the spectral reflectance distributions in the interpolated relationships of correspondence and the determined particle-size distributions; and
   (i)selecting the coating color by selecting from the determined depth indexes.

5. A method of selecting a coating color, according to any claim 2, 3 and 4, further comprising steps of:

(j)estimating on the basis of a plurality of predetermined relationships of correspondence a relationship of correspondence between a spectral reflectance distribution and a characteristic value of the selected coating color and

(k)reproducing the coating color by determining a quantity of each of all the component materials by characteristic values which are determined from the estimated relationship of correspondence.

FIG. 1

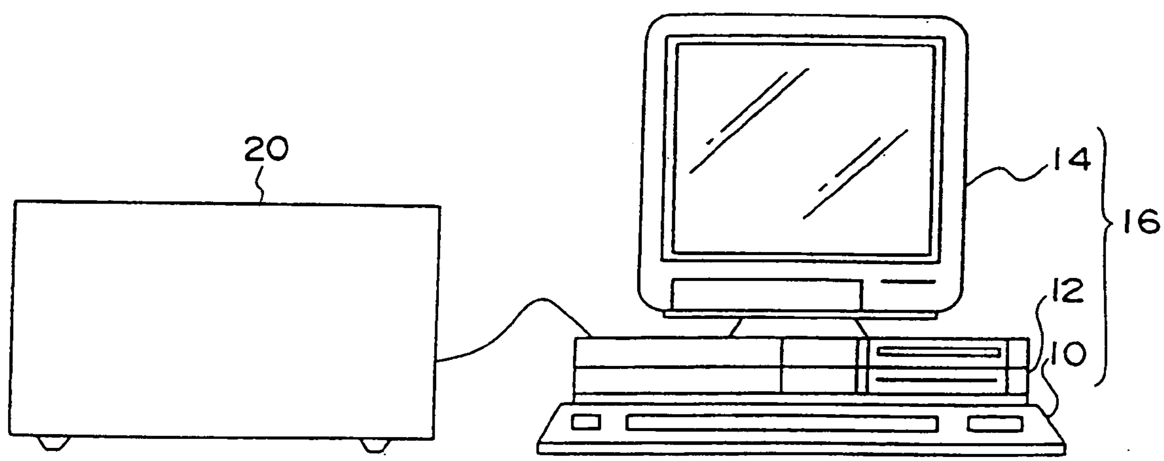


FIG. 2

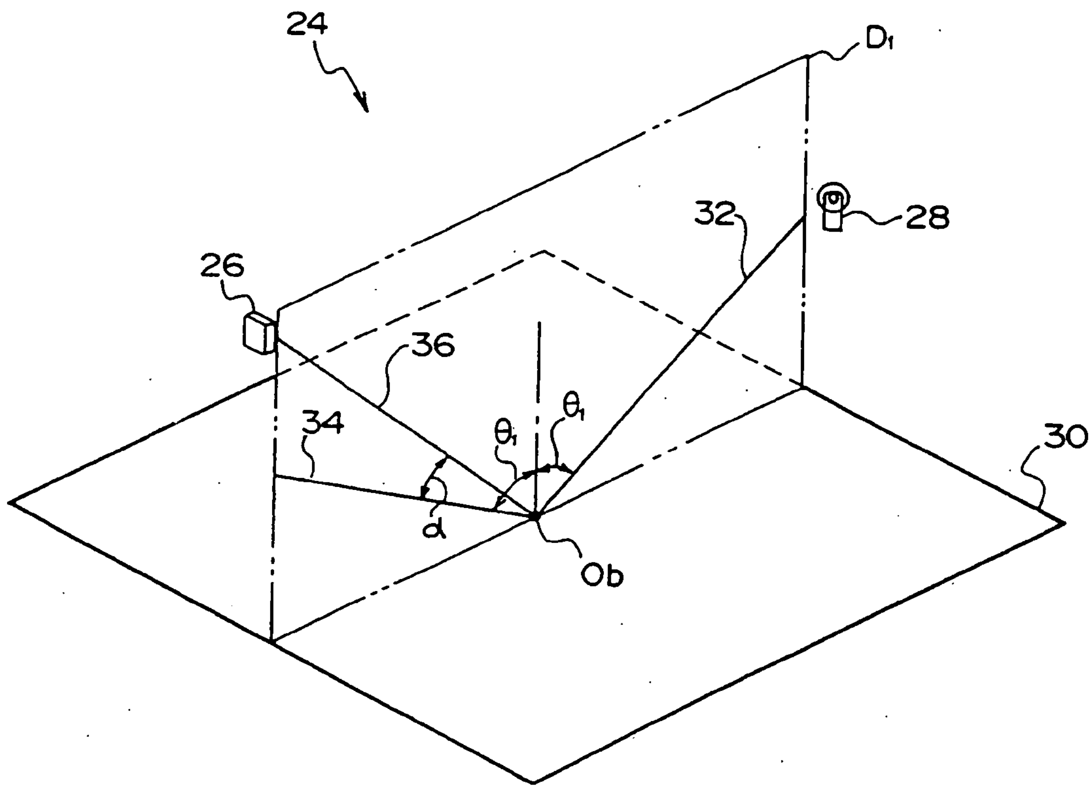


FIG. 3

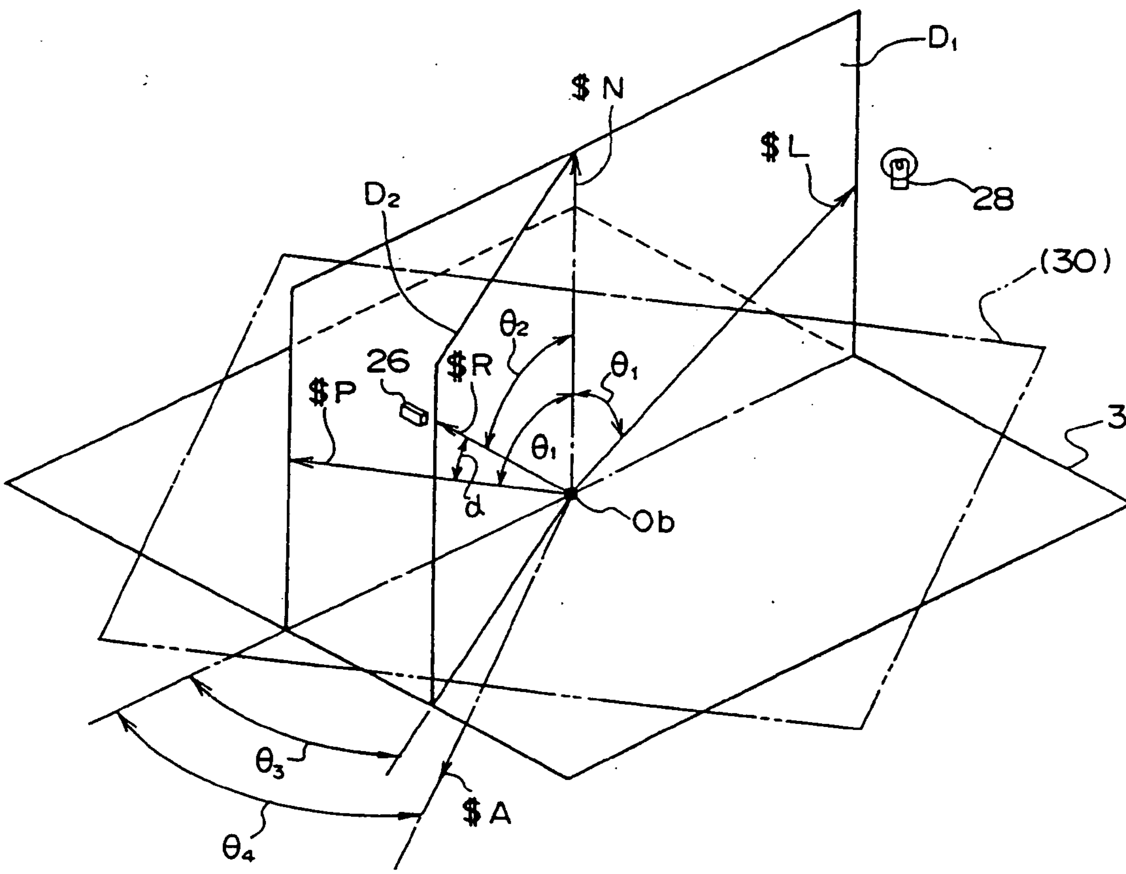


FIG. 4

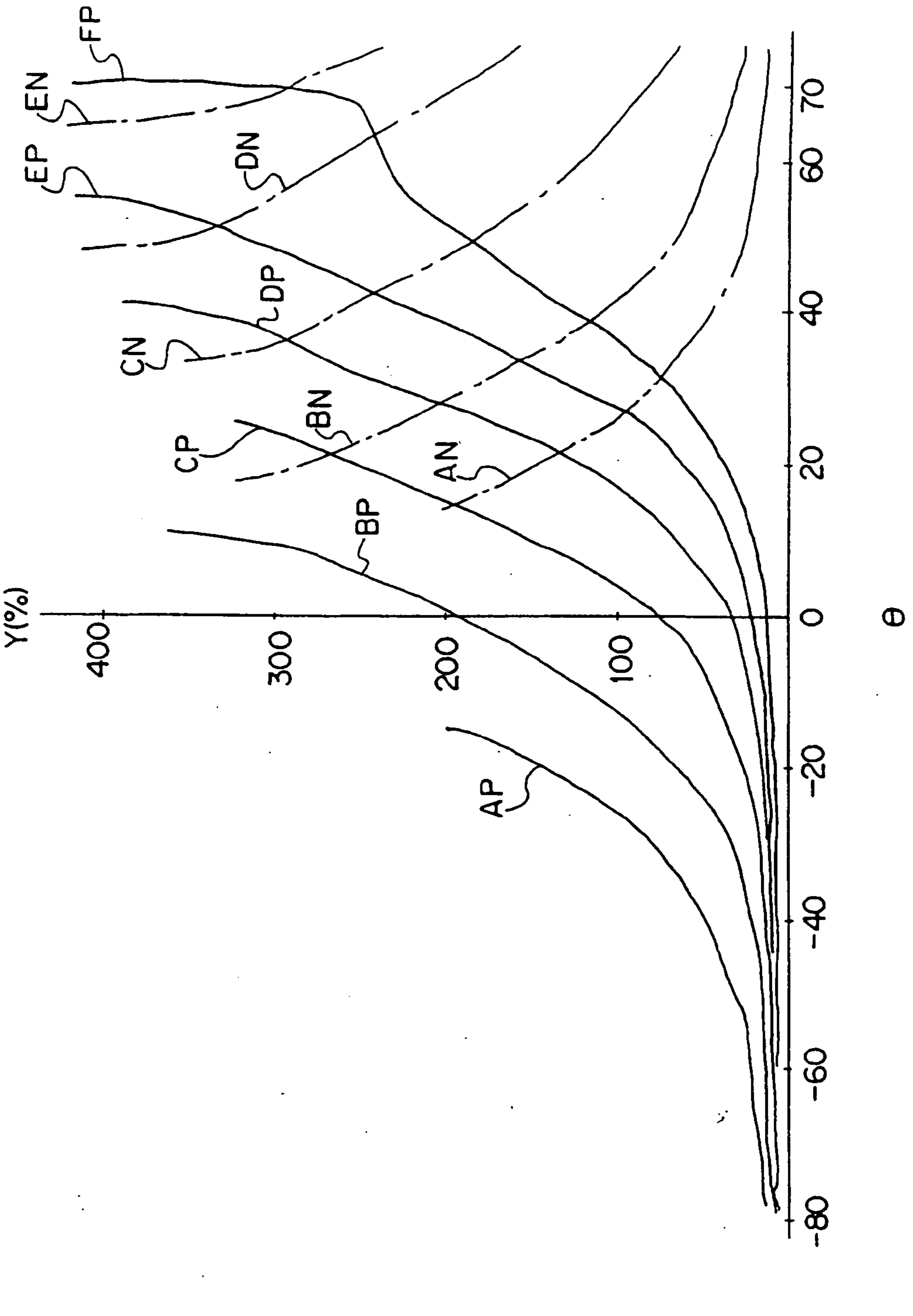

Y(%)
400
300
200
100
0
θ
-80
-60
-40
-20
0
20
40
60
70
AP
BP
CP
AN
BN
CN
DP
DN
EP
EN
FP

FIG. 5A

METALLIC COATING

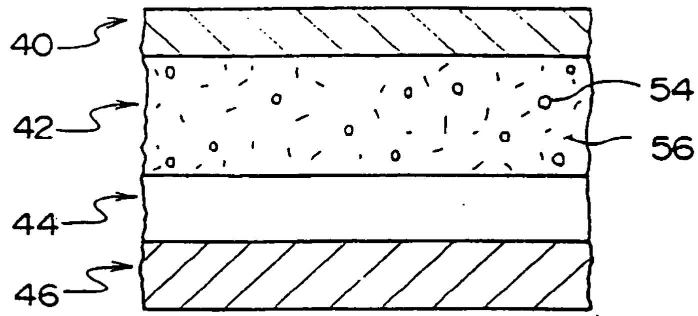


FIG. 5B

PEARL MICA COATING

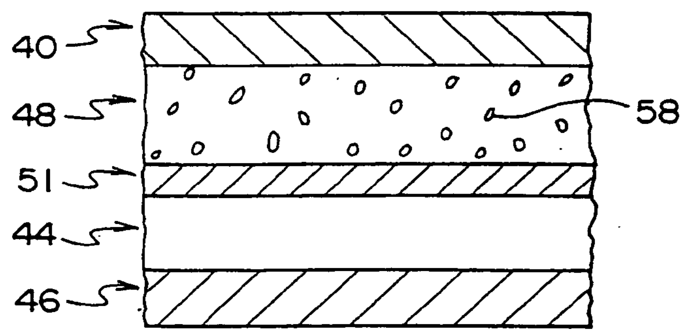


FIG. 5C

SOLID COATING

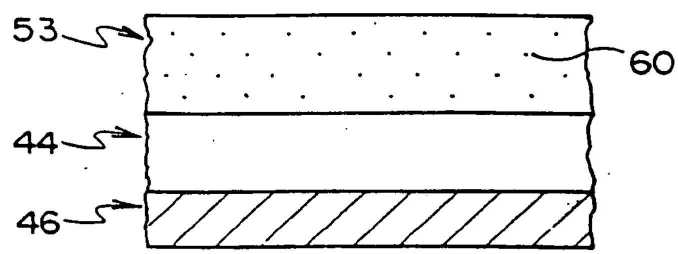


FIG. 6

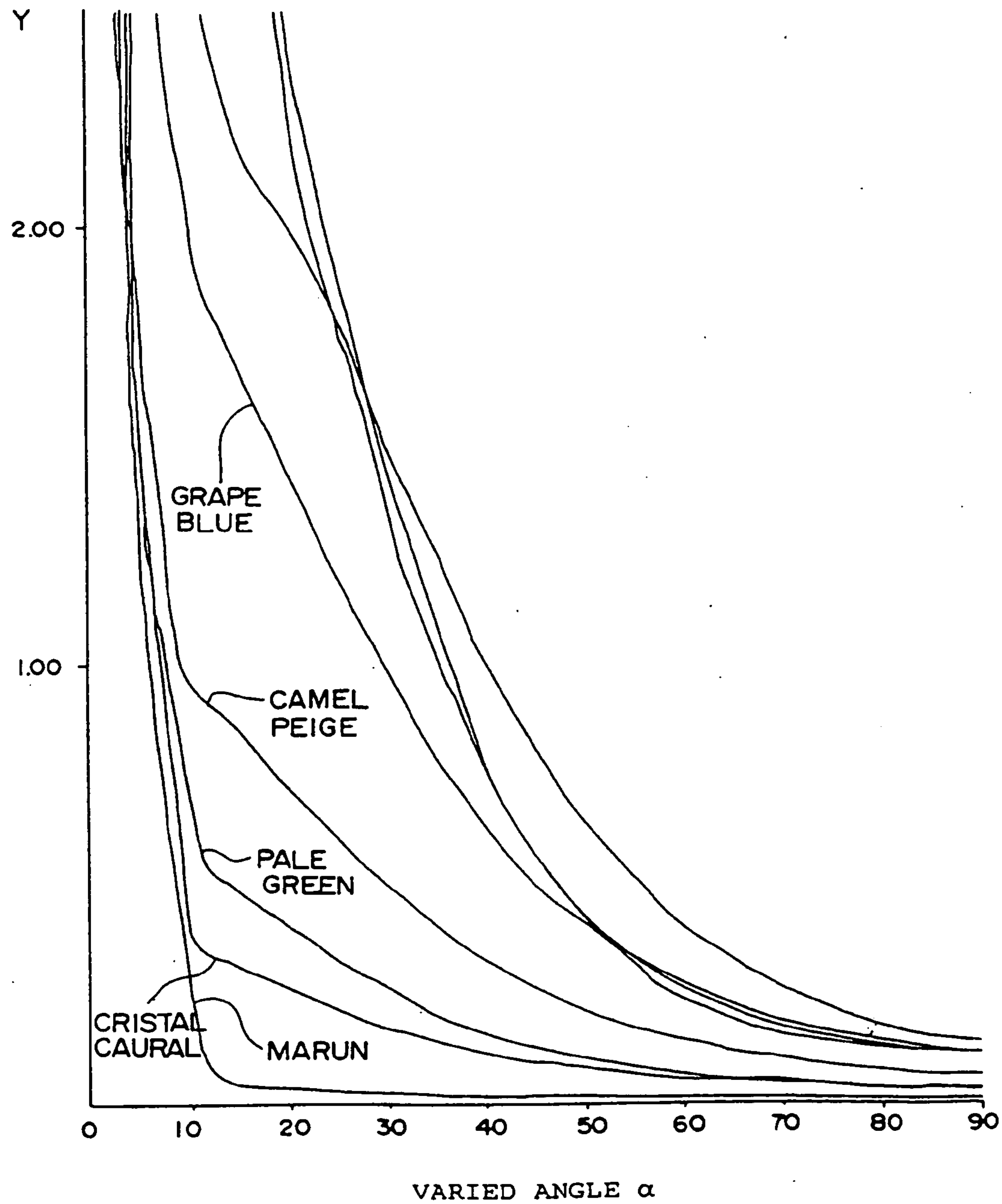

Y
2.00
1.00
GRAPE
BLUE
CAMEL
PEIGE
PALE
GREEN
CRISTAL
CAURAL
MARUN
0
10
20
30
40
50
60
70
80
90
VARIED ANGLE α

FIG. 7

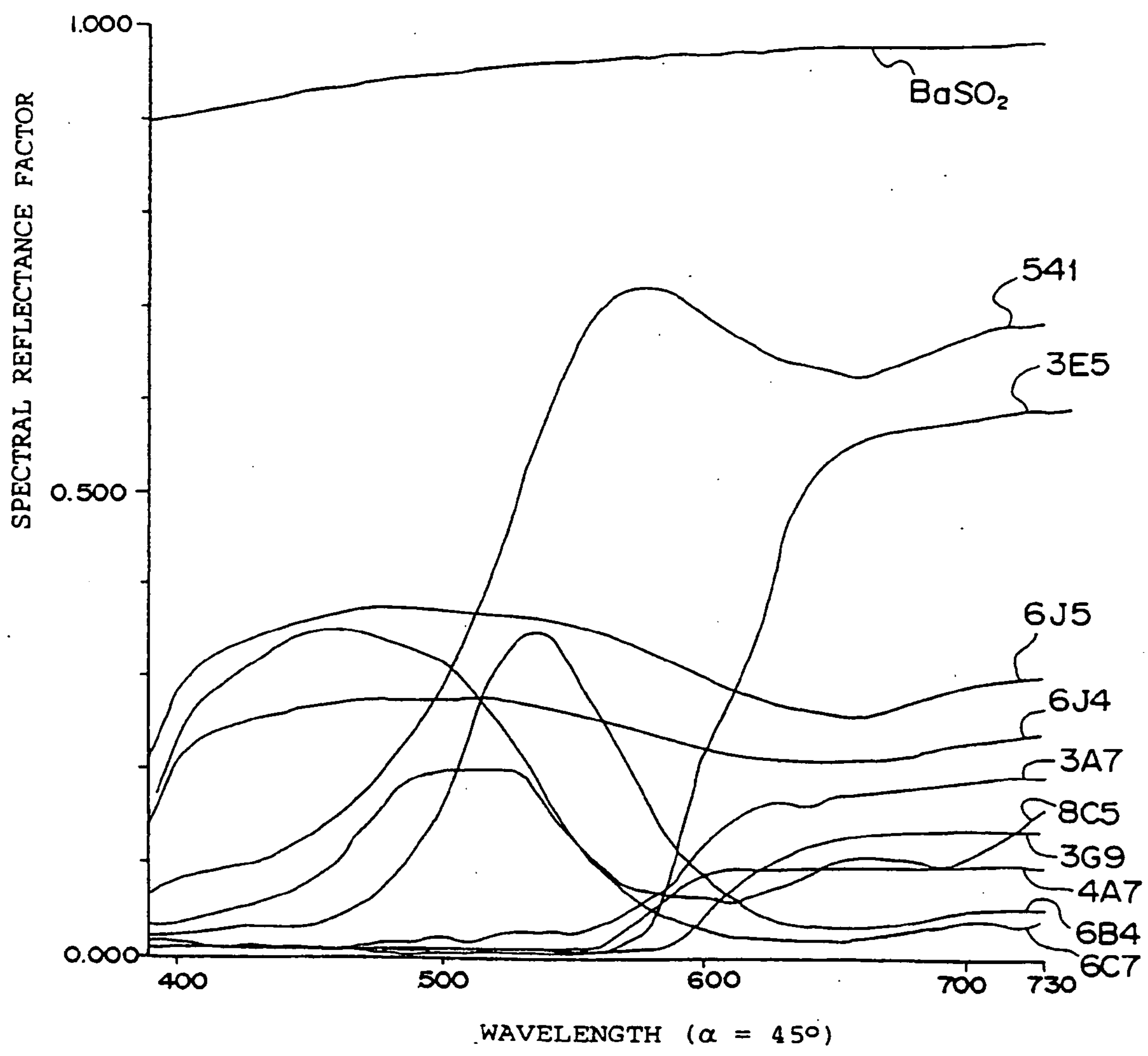

1.000
0.500
0.000
SPECTRAL REFLECTANCE FACTOR
400
500
600
700
730
WAVELENGTH (α = 45°)
BaSO2
541
3E5
6J5
6J4
3A7
8C5
3G9
4A7
6B4
6C7

FIG. 8

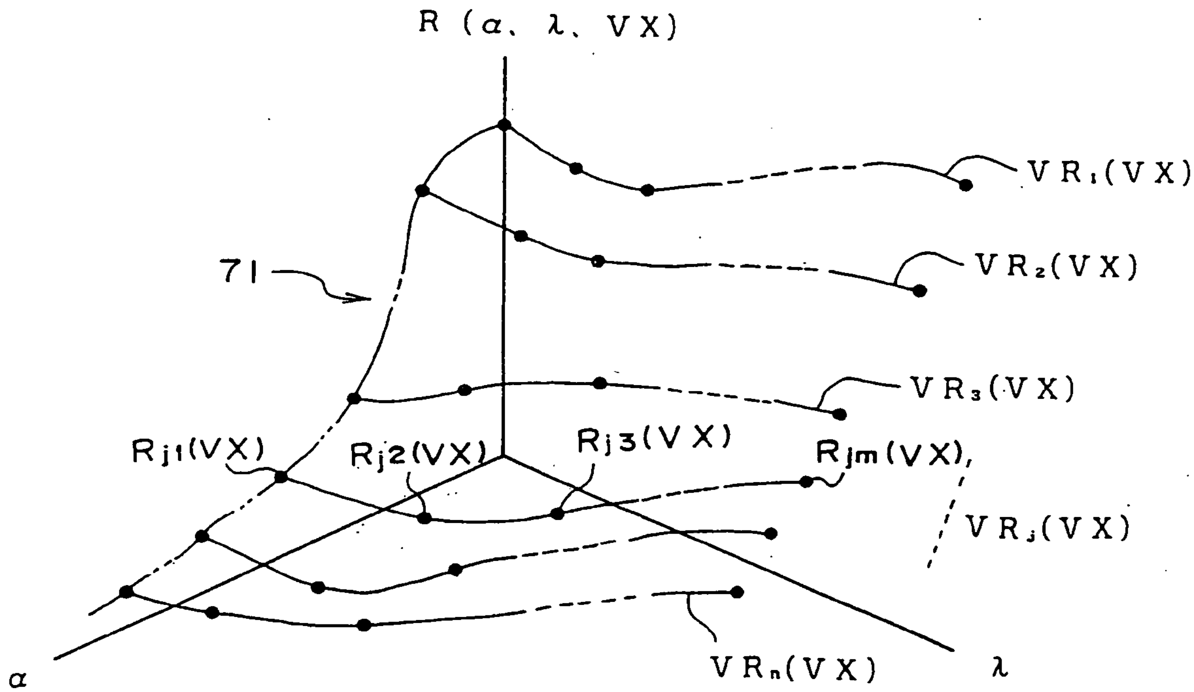

R (α、λ、VX)
VR₁(VX)
VR₂(VX)
71
VR₃(VX)
Rj1(VX)
Rj2(VX)
Rj3(VX)
Rjm(VX),
VRj(VX)
VRn(VX)
α
λ

FIG. 9

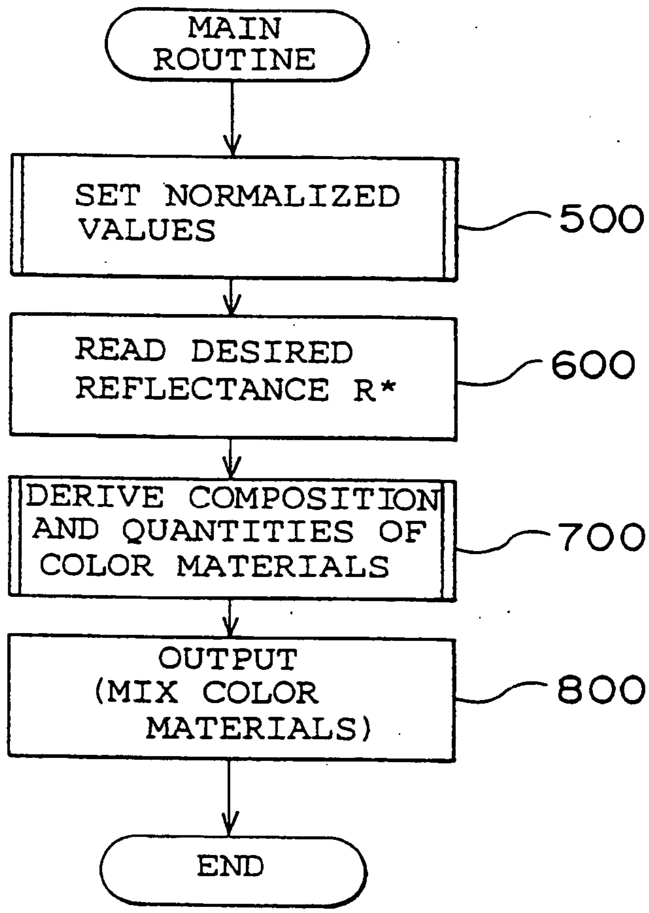

MAIN ROUTINE
SET NORMALIZED VALUES
500
READ DESIRED REFLECTANCE R*
600
DERIVE COMPOSITION AND QUANTITIES OF COLOR MATERIALS
700
OUTPUT (MIX COLOR MATERIALS)
800
END

FIG. 10

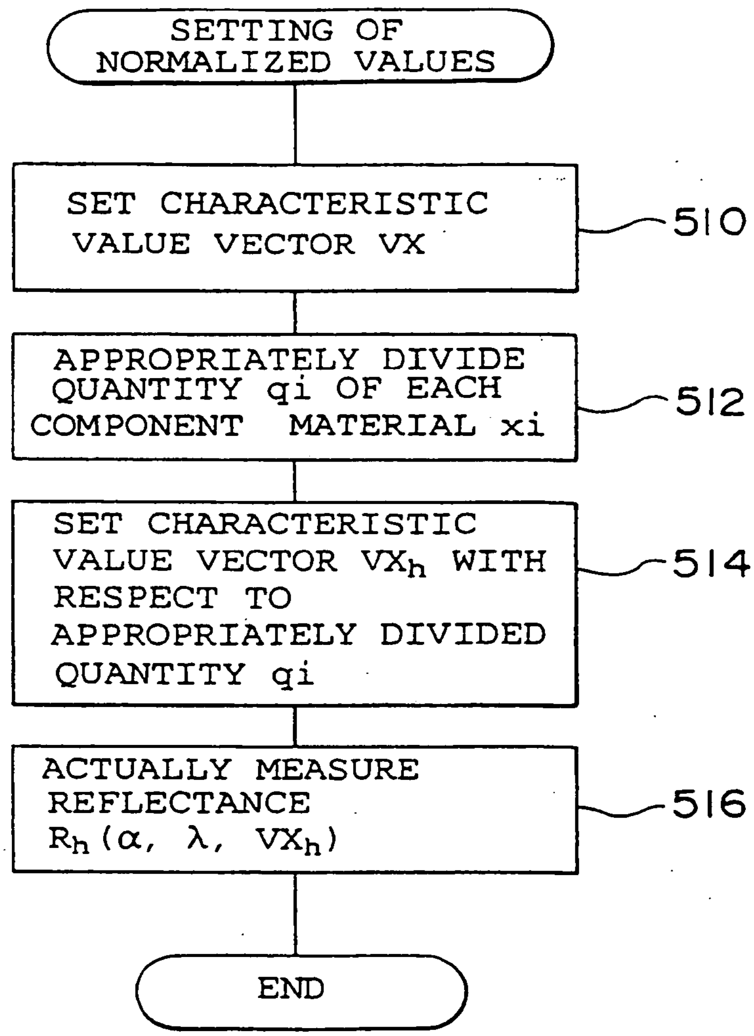
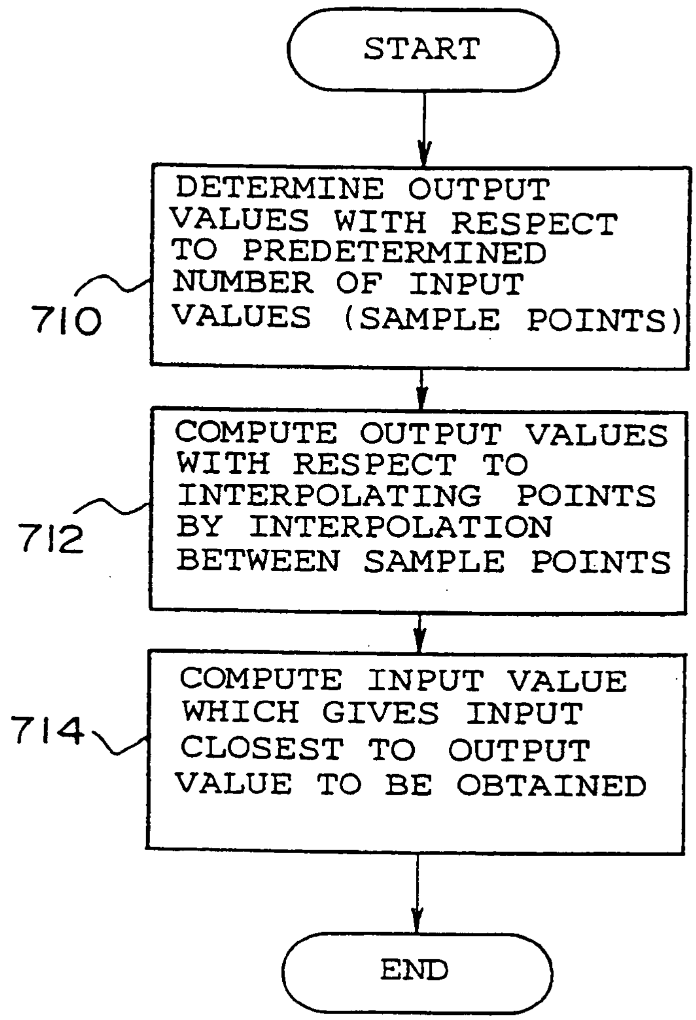

SETTING OF NORMALIZED VALUES
SET CHARACTERISTIC VALUE VECTOR VX
510
APPROPRIATELY DIVIDE QUANTITY qi OF EACH COMPONENT MATERIAL xi
512
SET CHARACTERISTIC VALUE VECTOR VX_h WITH RESPECT TO APPROPRIATELY DIVIDED QUANTITY qi
514
ACTUALLY MEASURE REFLECTANCE $R_h(\alpha, \lambda, VX_h)$
516
END

FIG. 11


START
DETERMINE OUTPUT VALUES WITH RESPECT TO PREDETERMINED NUMBER OF INPUT VALUES (SAMPLE POINTS)
710
COMPUTE OUTPUT VALUES WITH RESPECT TO INTERPOLATING POINTS BY INTERPOLATION BETWEEN SAMPLE POINTS
712
COMPUTE INPUT VALUE WHICH GIVES INPUT CLOSEST TO OUTPUT VALUE TO BE OBTAINED
714
END

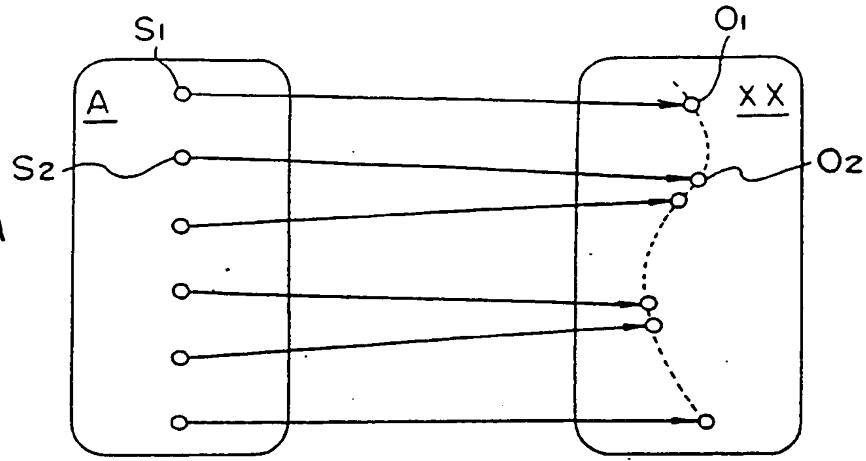


FIG. 12A

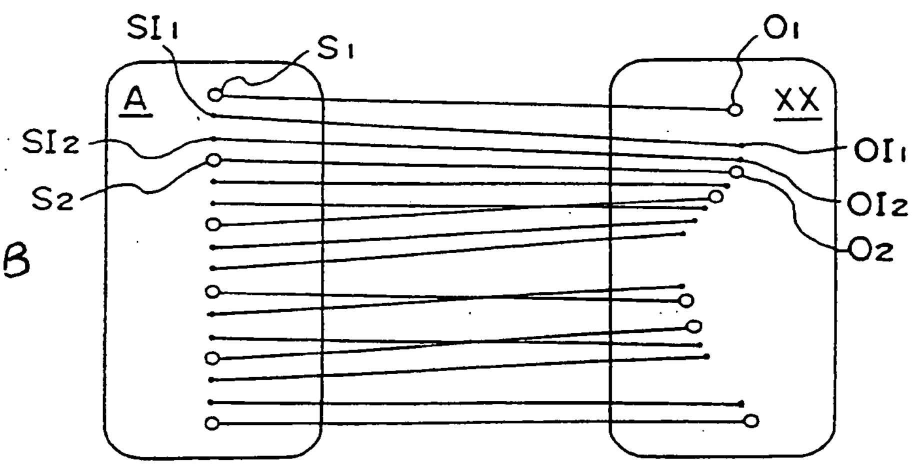


FIG. 12B

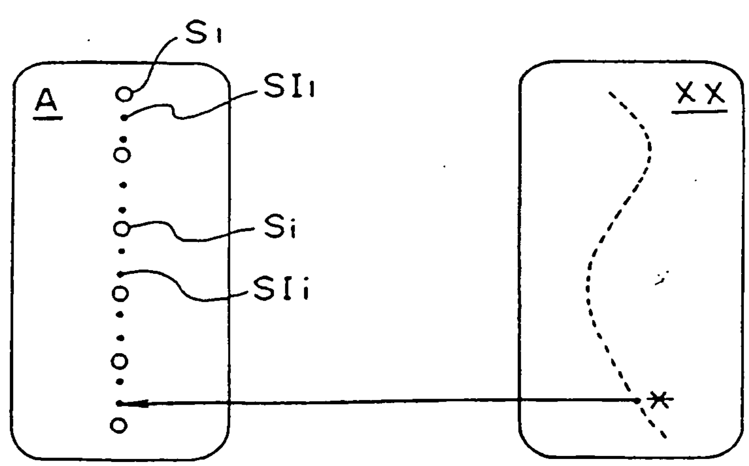


FIG. 12C

FIG. 13

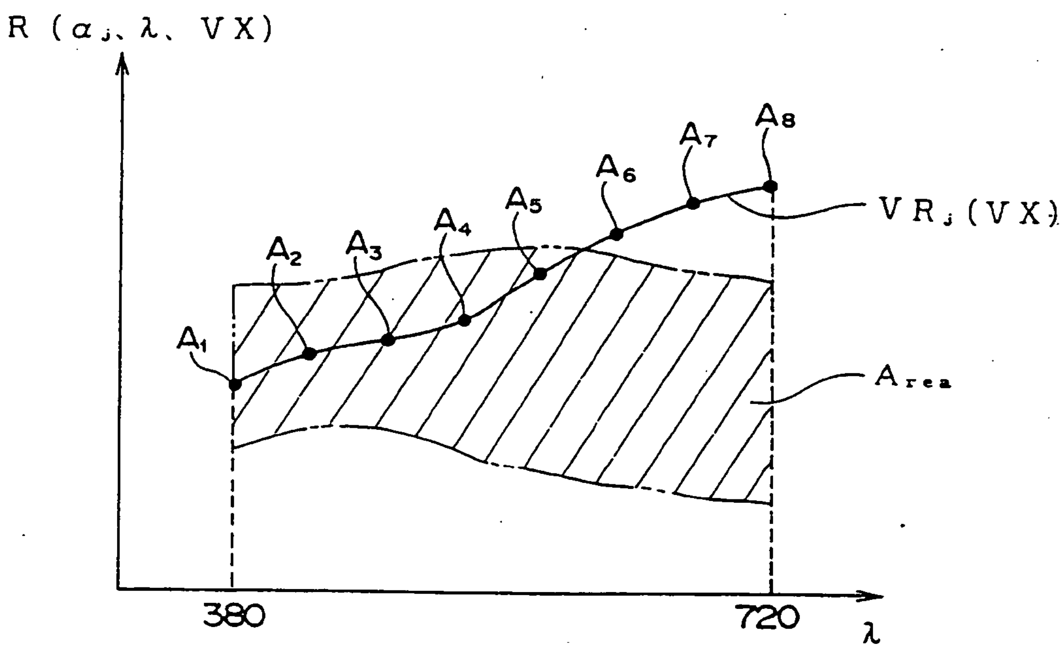


FIG. 14

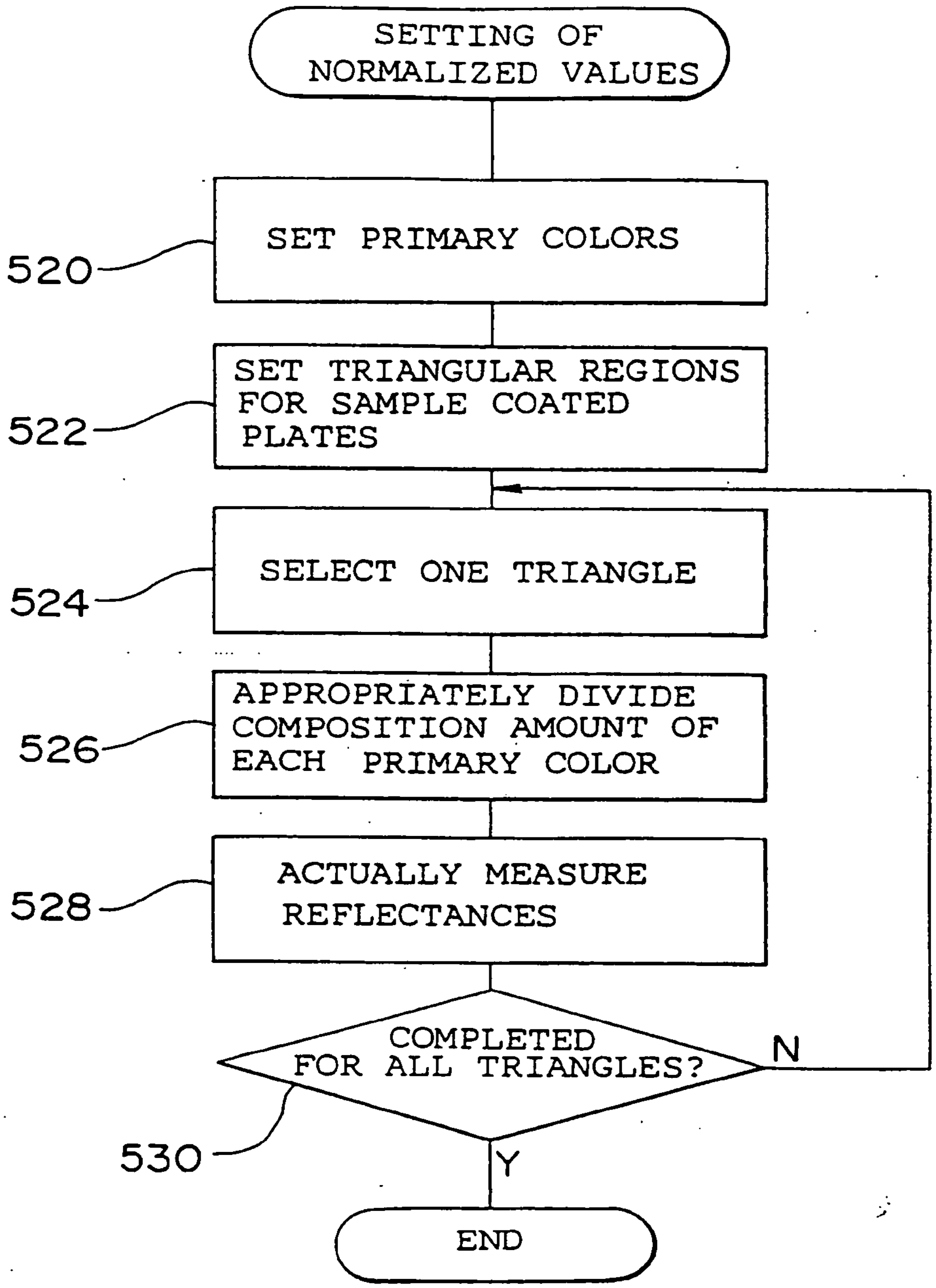

SETTING OF NORMALIZED VALUES
520
SET PRIMARY COLORS
522
SET TRIANGULAR REGIONS FOR SAMPLE COATED PLATES
524
SELECT ONE TRIANGLE
526
APPROPRIATELY DIVIDE COMPOSITION AMOUNT OF EACH PRIMARY COLOR
528
ACTUALLY MEASURE REFLECTANCES
530
COMPLETED FOR ALL TRIANGLES?
N
Y
END

FIG. 15

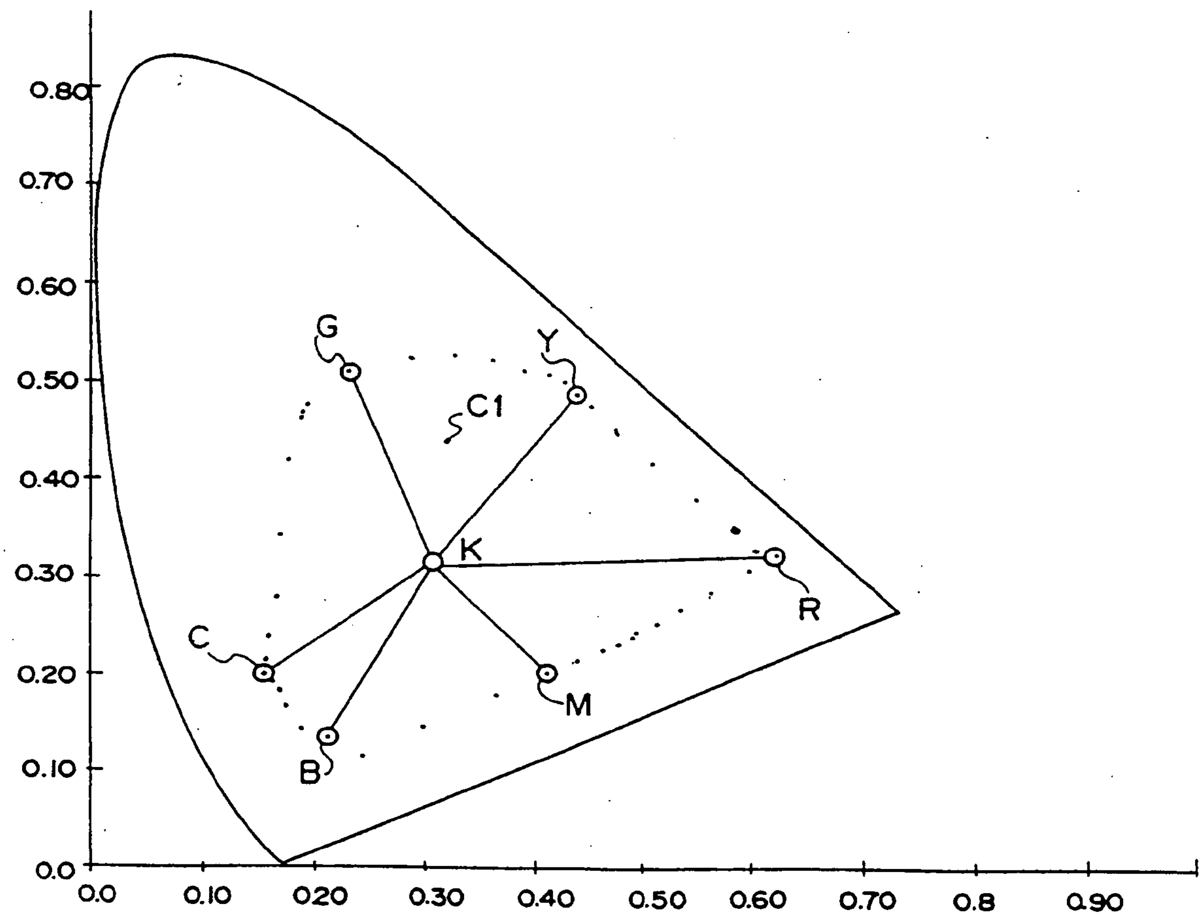

0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.0
0.0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.8
0.90
G
Y
C1
K
R
C
M
B

FIG. 16

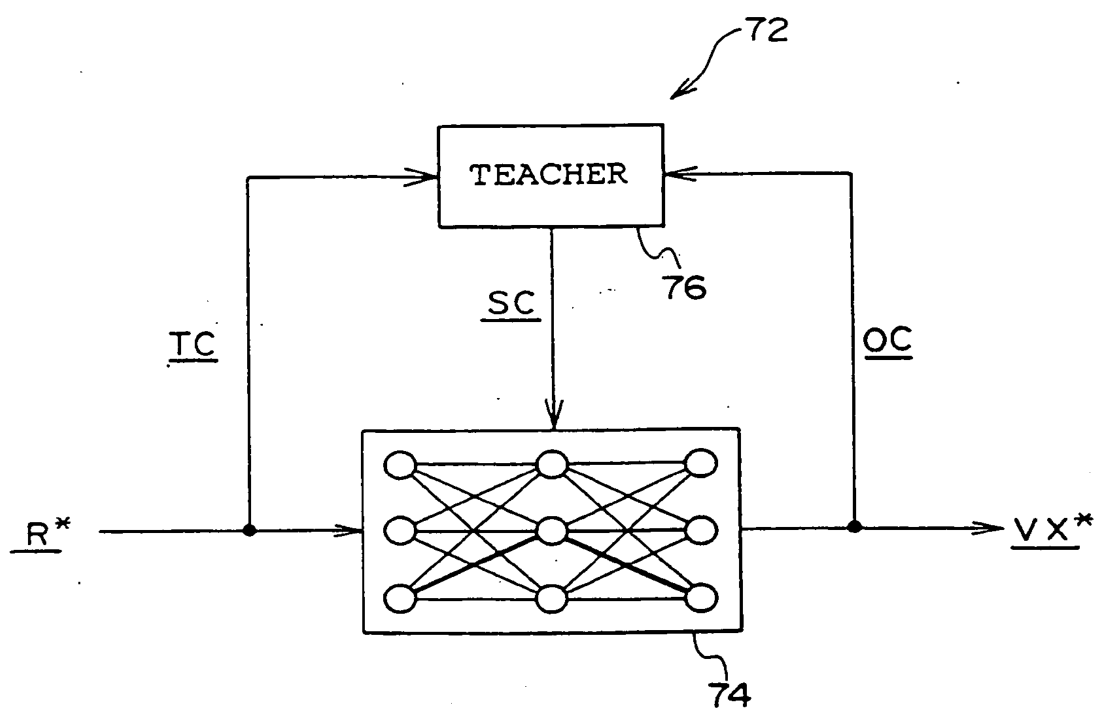


FIG. 17

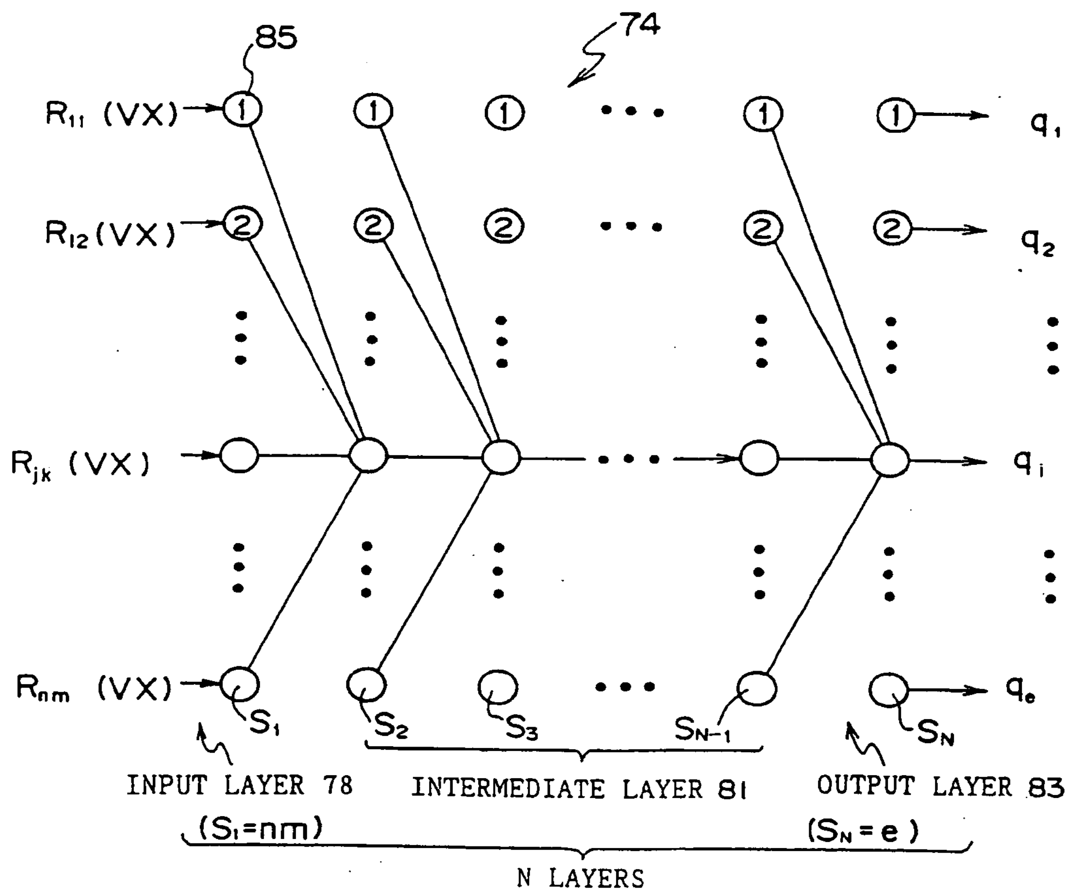

74
85
R11 (VX)
R12 (VX)
Rjk (VX)
Rnm (VX)
q1
q2
qi
qe
S1
S2
S3
SN-1
SN
INPUT LAYER 78
INTERMEDIATE LAYER 81
OUTPUT LAYER 83
(S1=nm)
(SN = e)
N LAYERS

FIG. 18

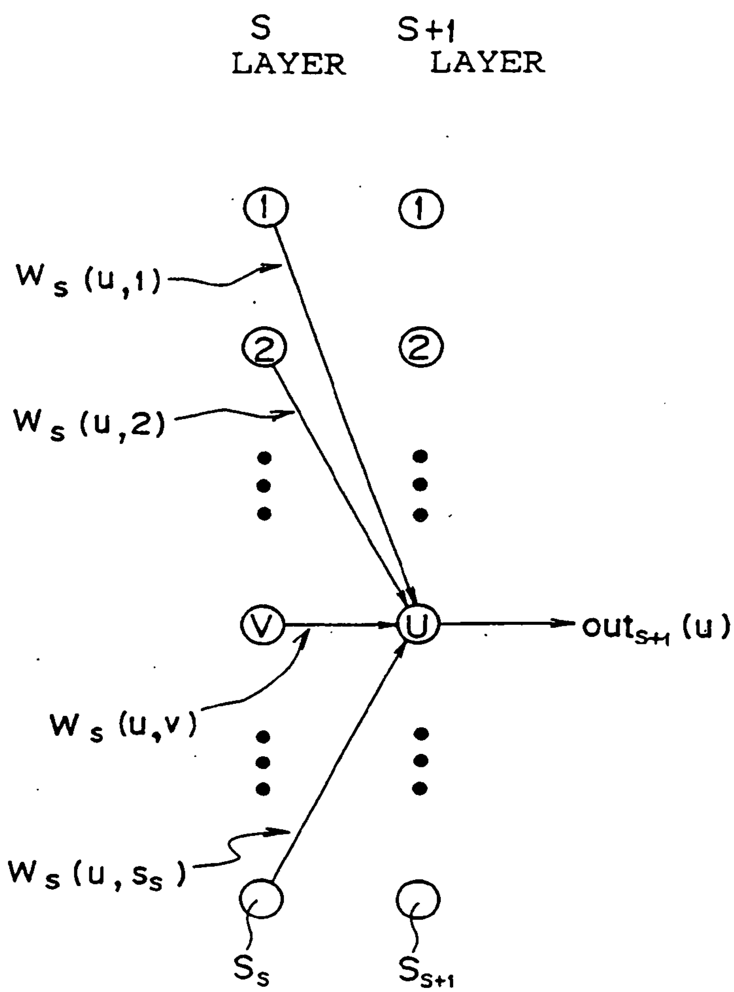


FIG. 19

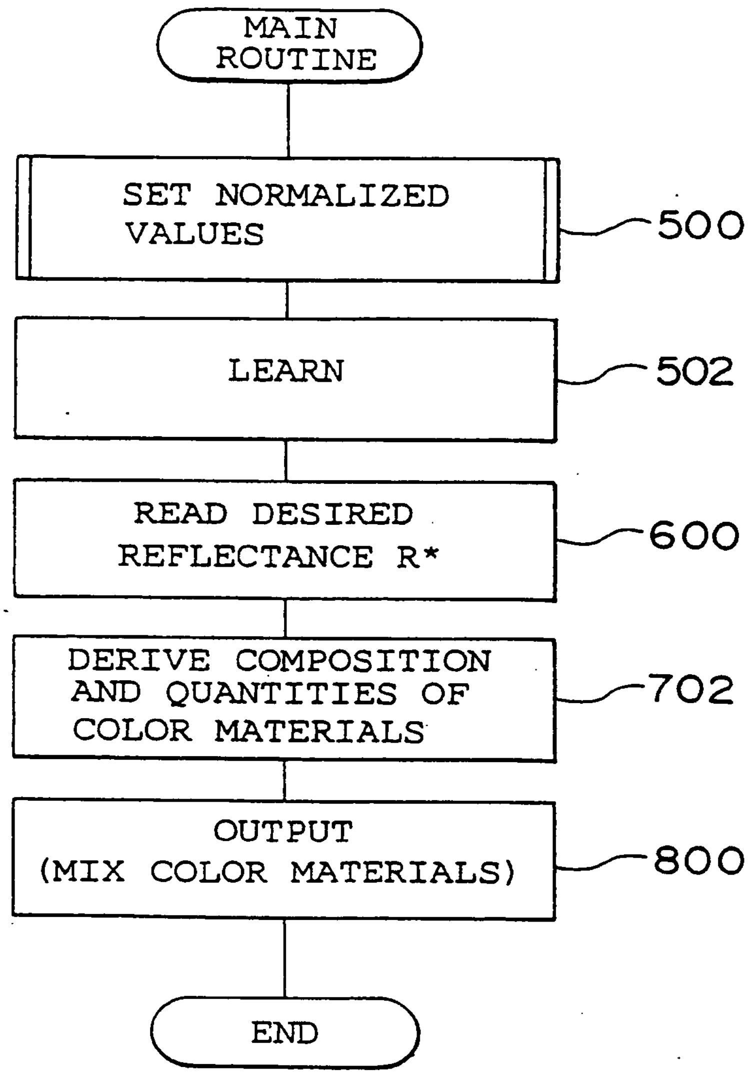

MAIN ROUTINE
SET NORMALIZED VALUES
500
LEARN
502
READ DESIRED REFLECTANCE R*
600
DERIVE COMPOSITION AND QUANTITIES OF COLOR MATERIALS
702
OUTPUT (MIX COLOR MATERIALS)
800
END

FIG. 20

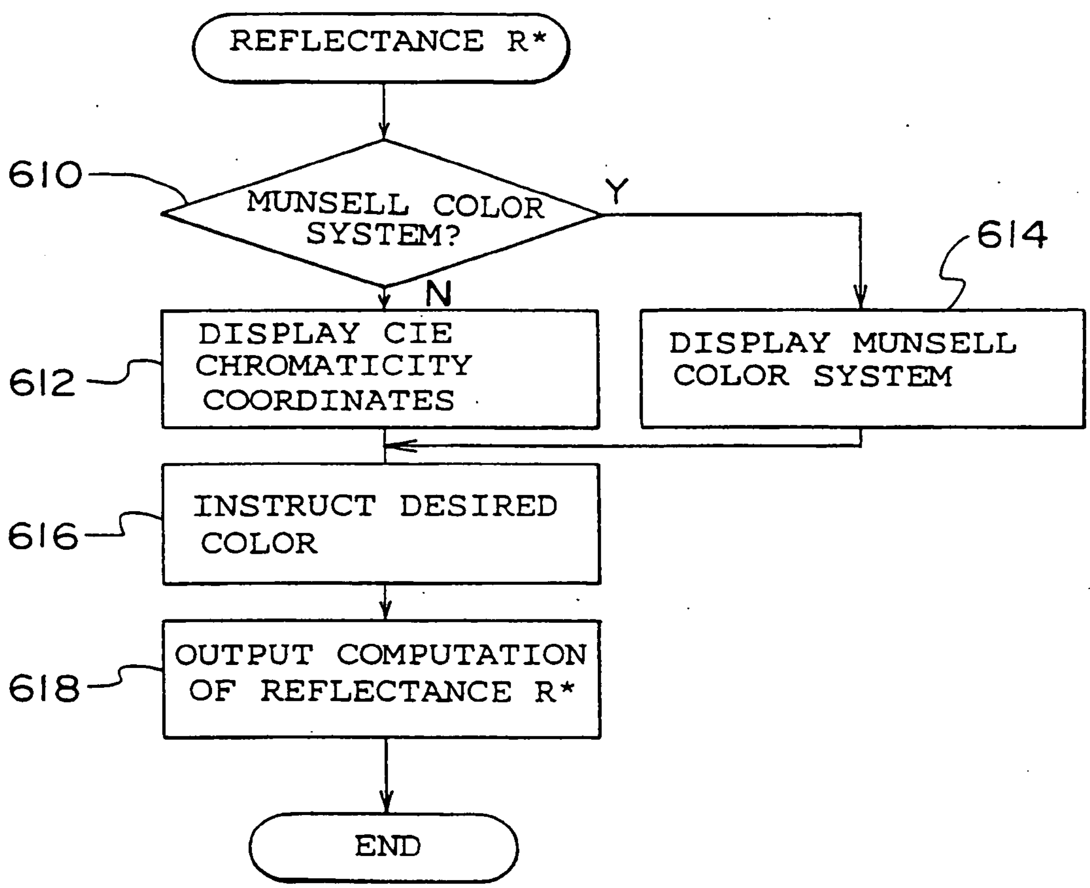

REFLECTANCE R*
610
MUNSELL COLOR SYSTEM?
Y
N
614
612
DISPLAY CIE CHROMATICITY COORDINATES
DISPLAY MUNSELL COLOR SYSTEM
616
INSTRUCT DESIRED COLOR
618
OUTPUT COMPUTATION OF REFLECTANCE R*
END

FIG. 21

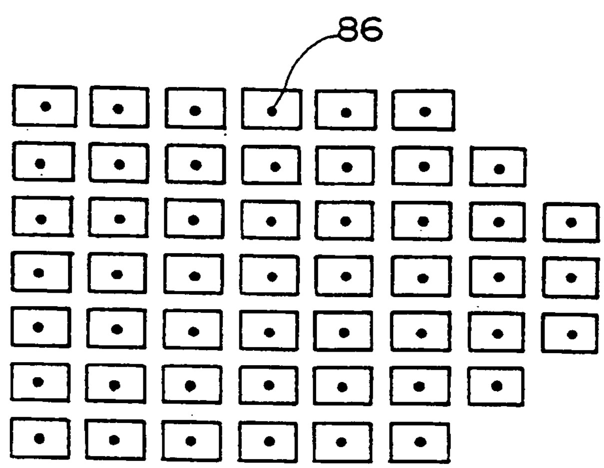


FIG. 22

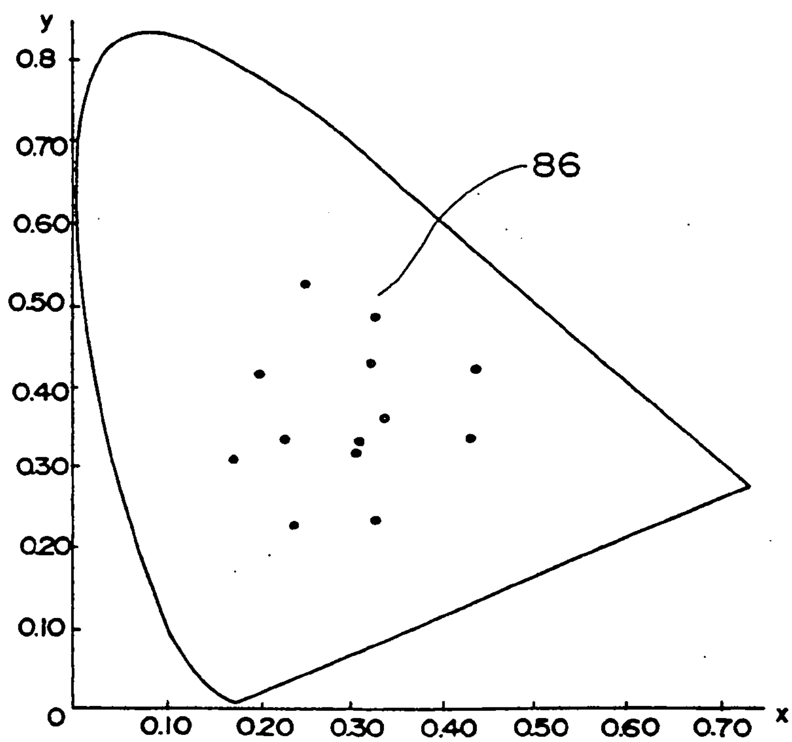


FIG. 23

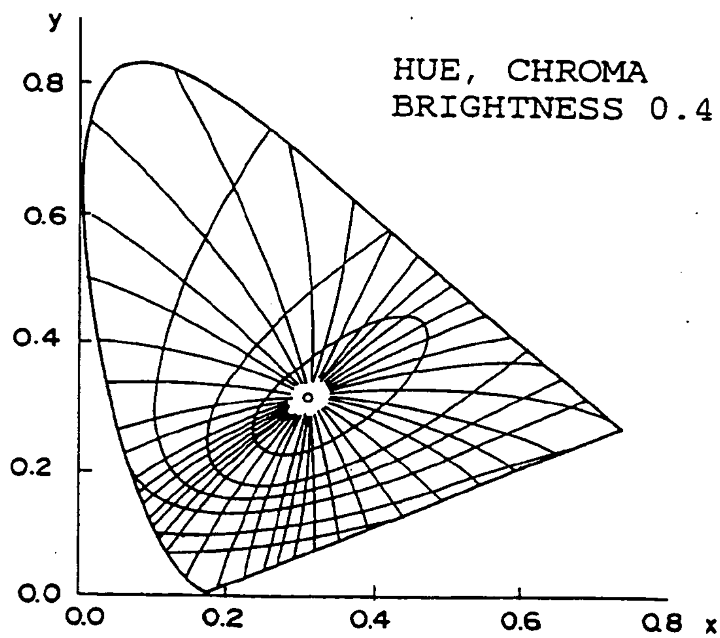


FIG. 24

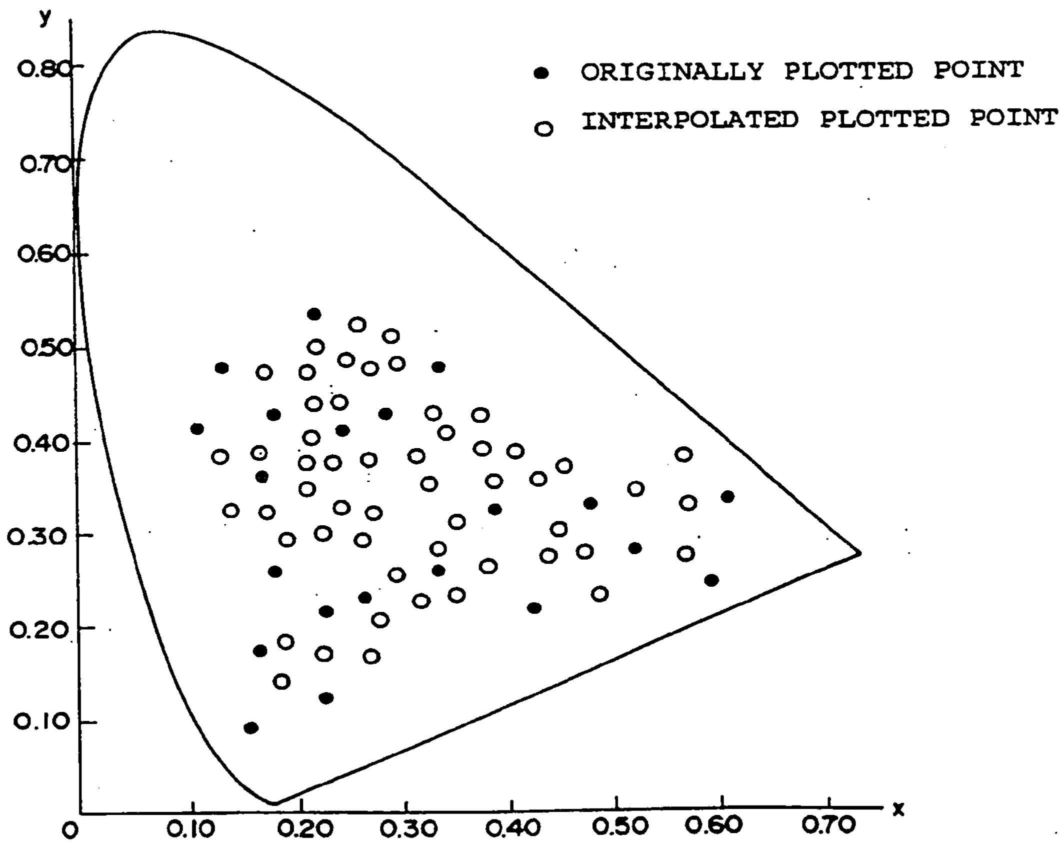

y
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
x
ORIGINALLY PLOTTED POINT
INTERPOLATED PLOTTED POINT

FIG. 25

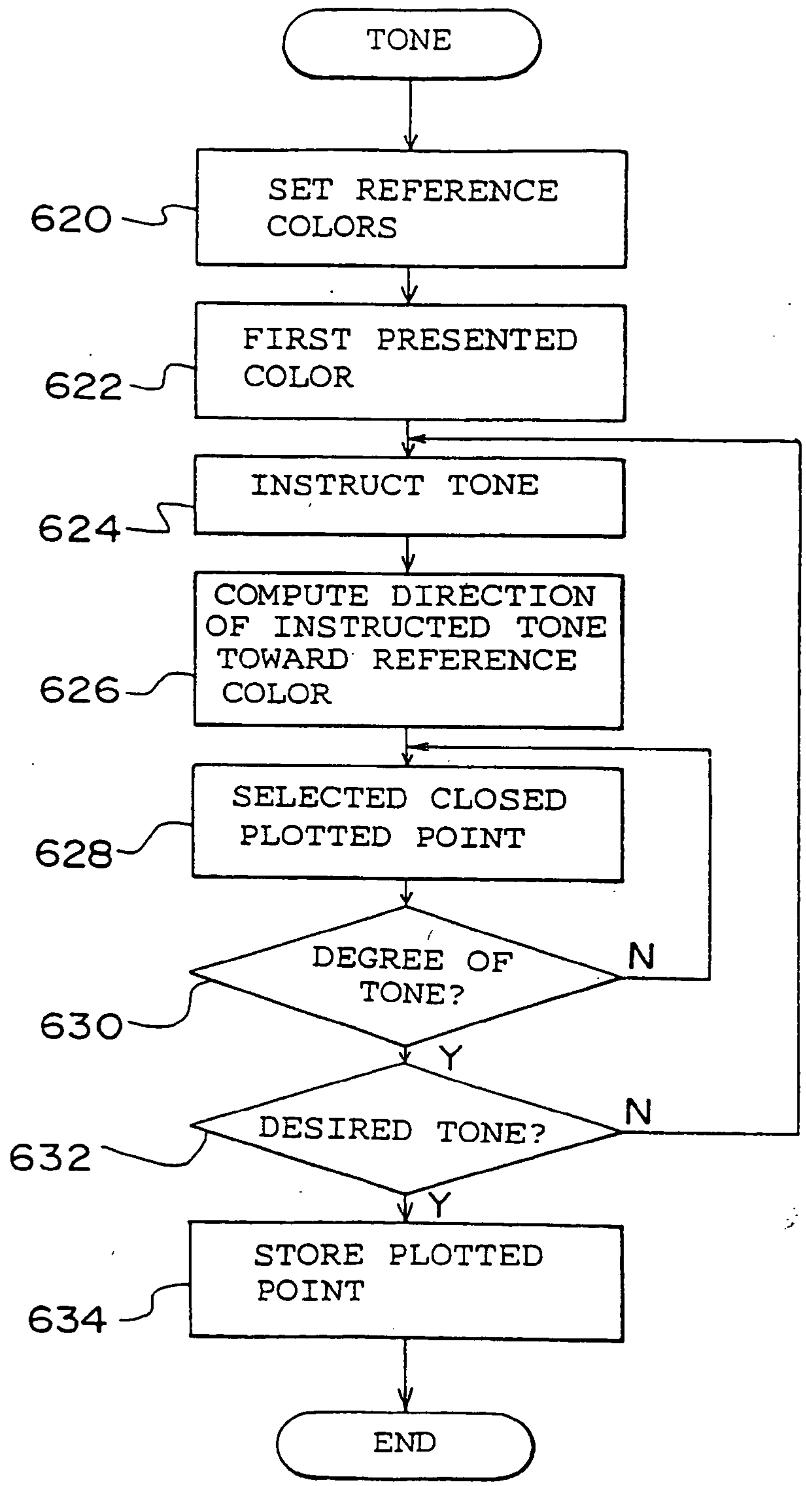

TONE
SET REFERENCE COLORS
620
FIRST PRESENTED COLOR
622
INSTRUCT TONE
624
COMPUTE DIRECTION OF INSTRUCTED TONE TOWARD REFERENCE COLOR
626
SELECTED CLOSED PLOTTED POINT
628
DEGREE OF TONE?
630
N
Y
DESIRED TONE?
632
N
Y
STORE PLOTTED POINT
634
END

FIG. 26

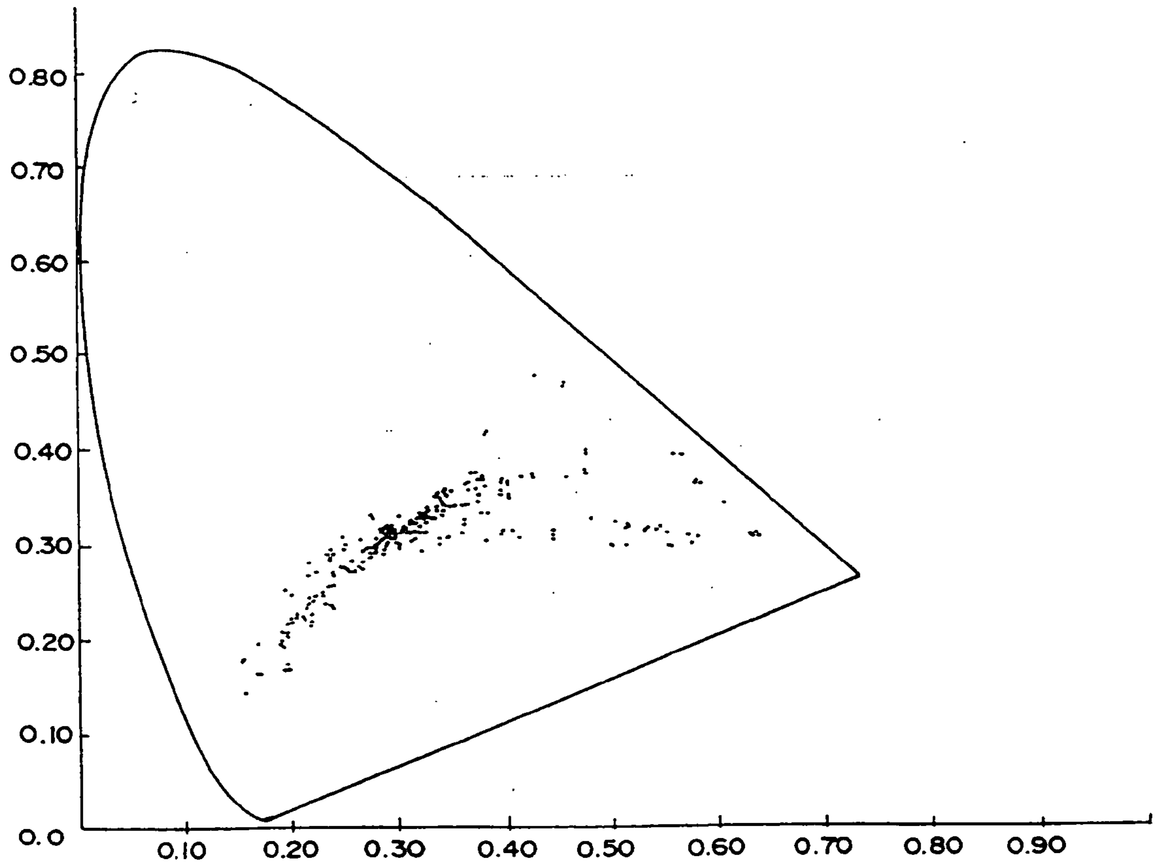

0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.0
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90

FIG. 27

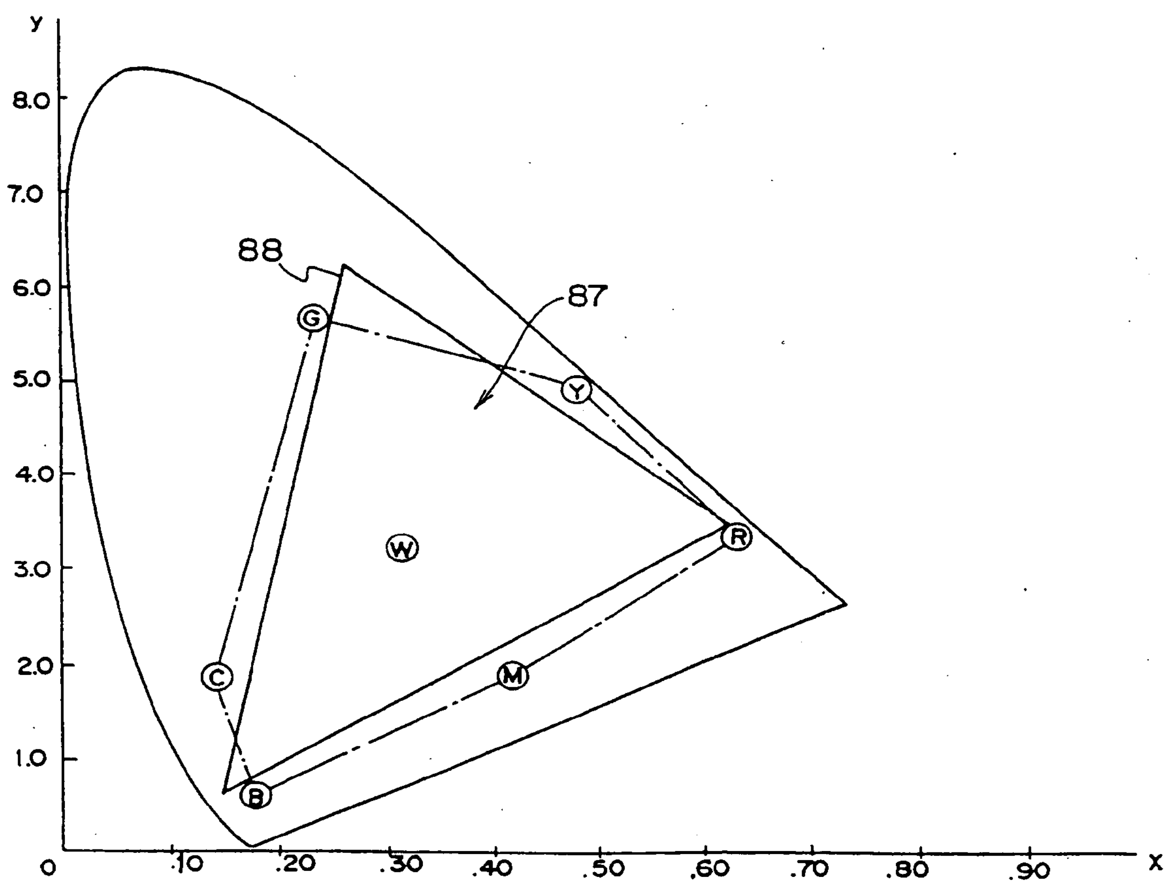


FIG. 28

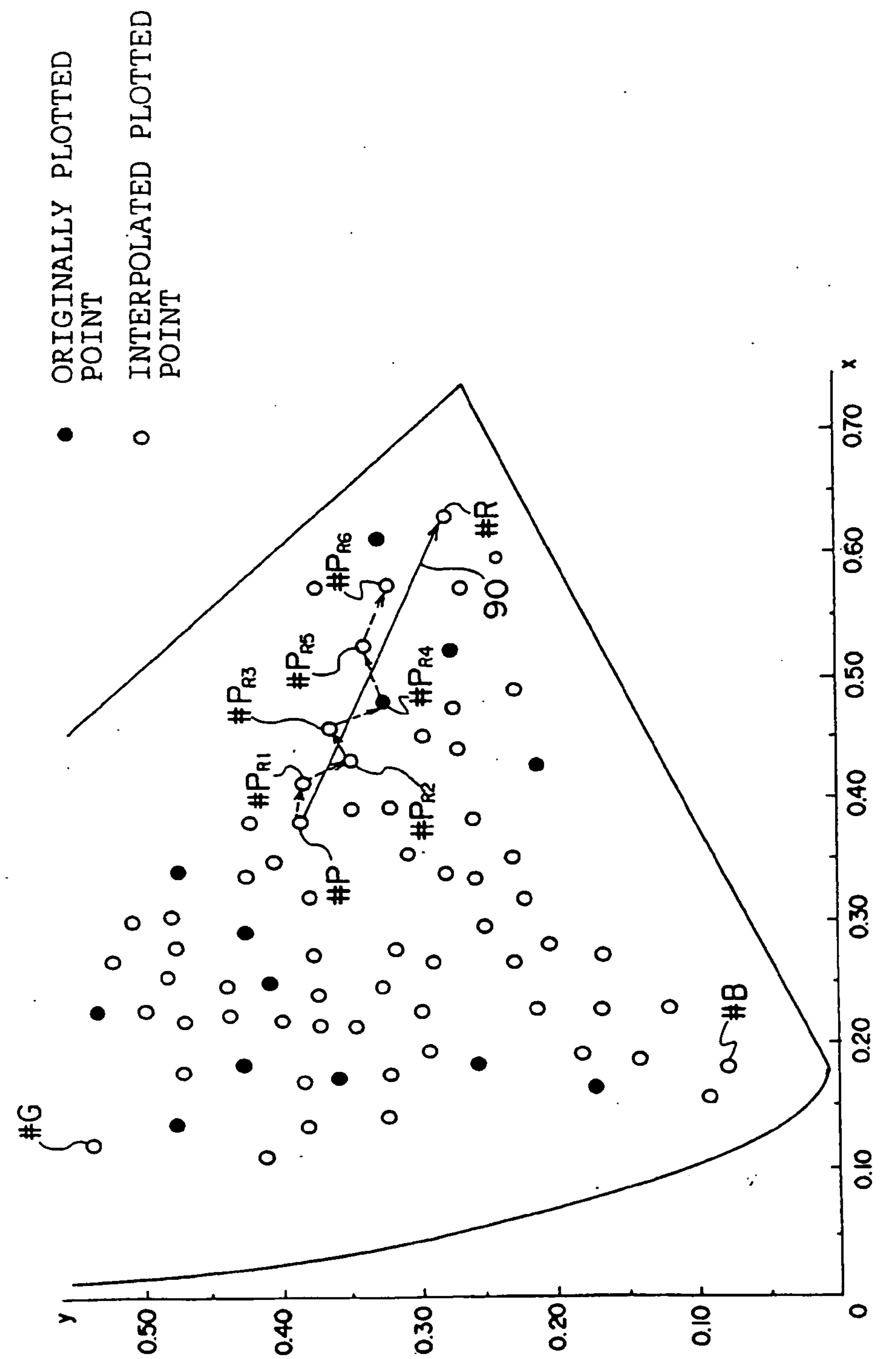

ORIGINALLY PLOTTED POINT
INTERPOLATED PLOTTED POINT
#G
#B
#R
#P
$\#P_{R1}$
$\#P_{R2}$
$\#P_{R3}$
$\#P_{R4}$
$\#P_{R5}$
$\#P_{R6}$
90
x
y
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70

FIG. 29

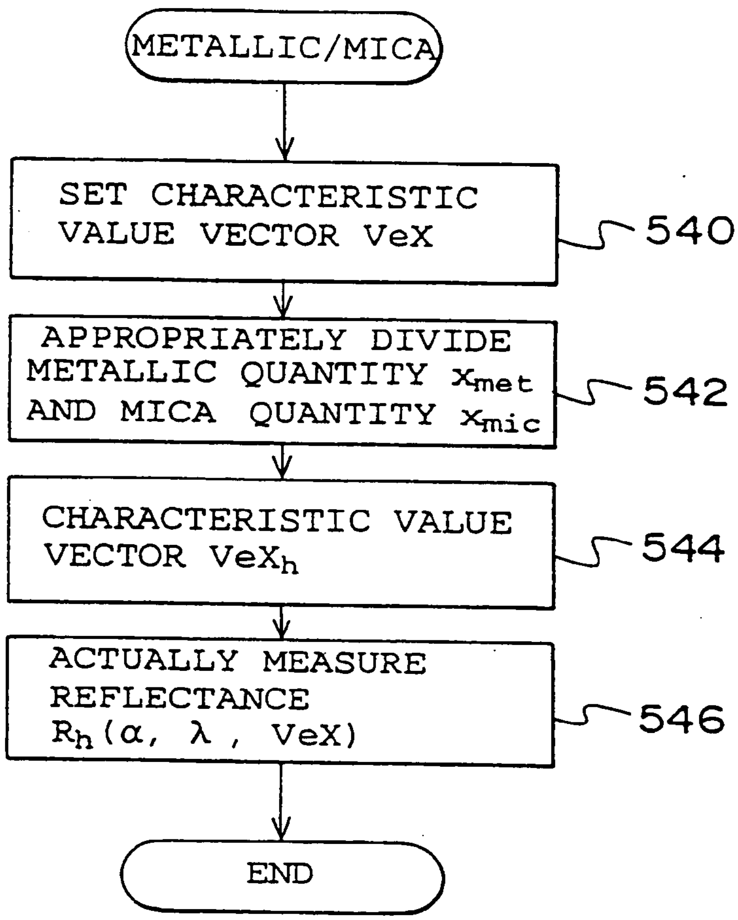

METALLIC/MICA
SET CHARACTERISTIC VALUE VECTOR VeX
540
APPROPRIATELY DIVIDE METALLIC QUANTITY x_{met} AND MICA QUANTITY x_{mic}
542
CHARACTERISTIC VALUE VECTOR VeX_h
544
ACTUALLY MEASURE REFLECTANCE $R_h(\alpha, \lambda, VeX)$
546
END

FIG. 30

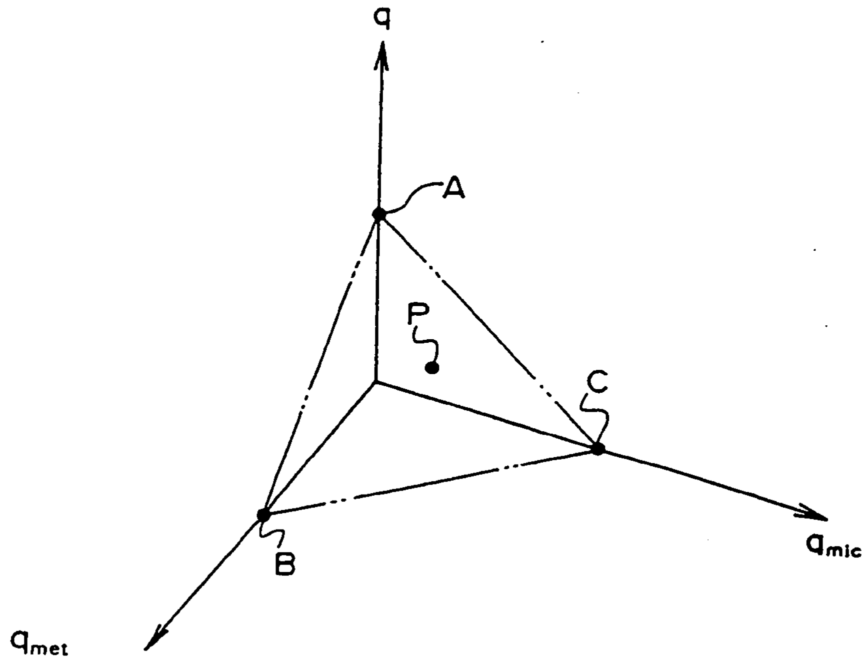


FIG. 31

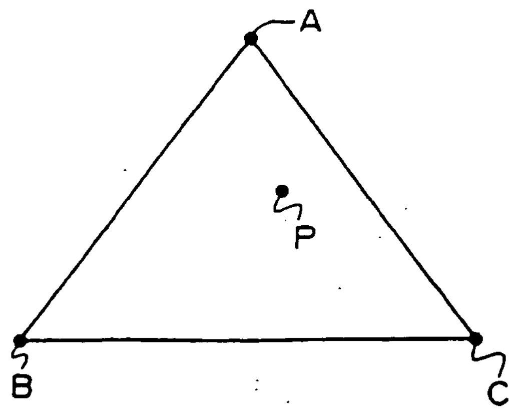


FIG. 32

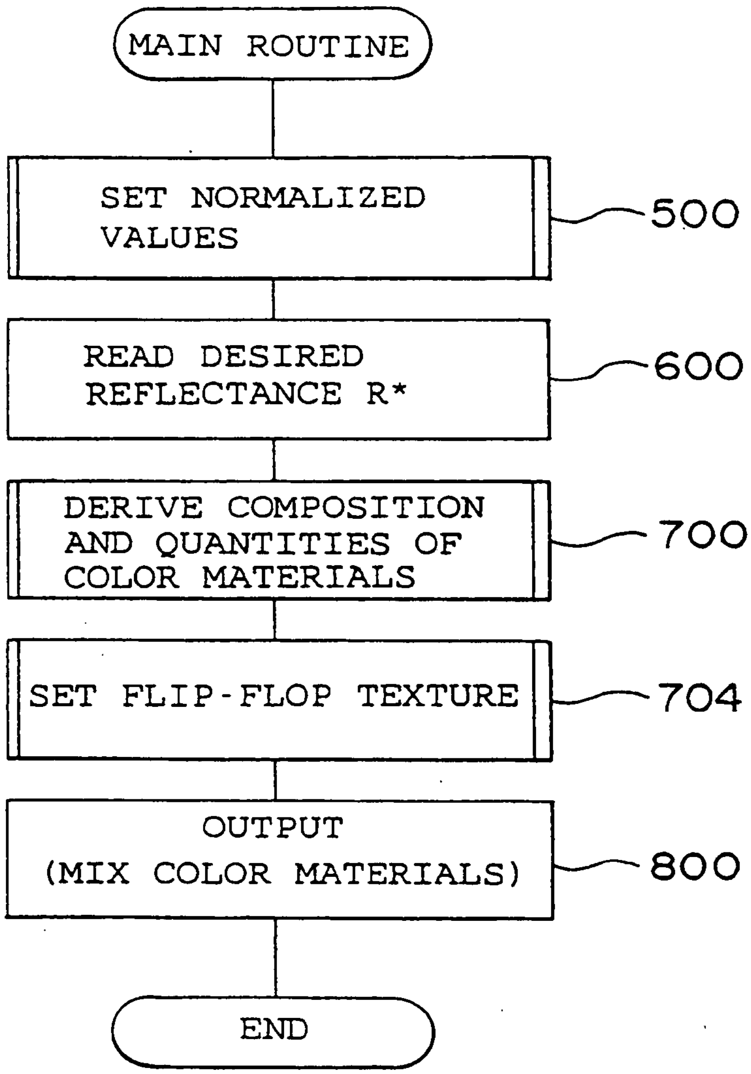

MAIN ROUTINE
SET NORMALIZED VALUES
500
READ DESIRED REFLECTANCE R*
600
DERIVE COMPOSITION AND QUANTITIES OF COLOR MATERIALS
700
SET FLIP-FLOP TEXTURE
704
OUTPUT (MIX COLOR MATERIALS)
800
END

FIG. 33

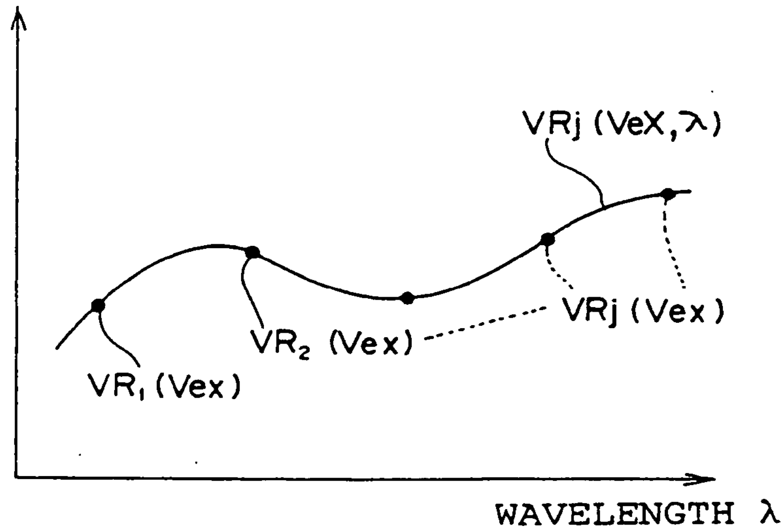

VRj (VeX, λ)
VRj (Vex)
VR₂ (Vex)
VR₁ (Vex)
WAVELENGTH λ

FIG. 34

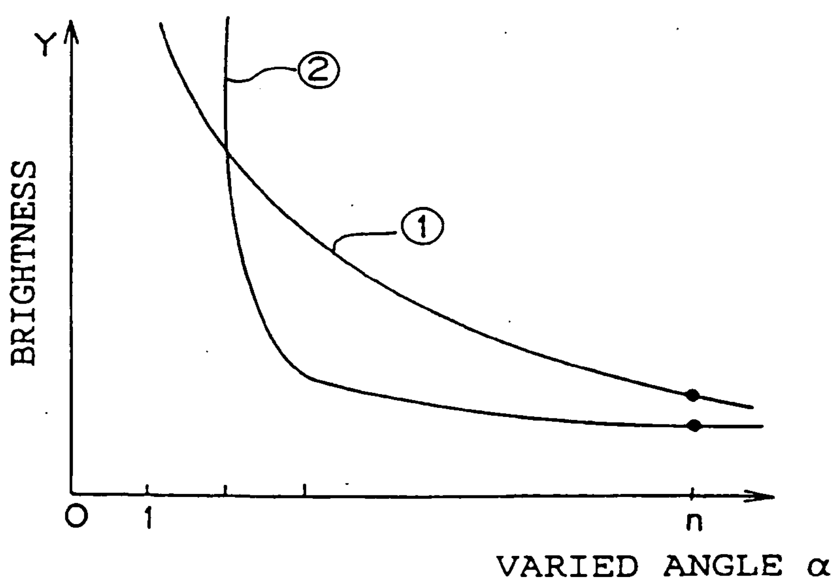

Y
BRIGHTNESS
2
1
O
1
n
VARIED ANGLE α

FIG. 35

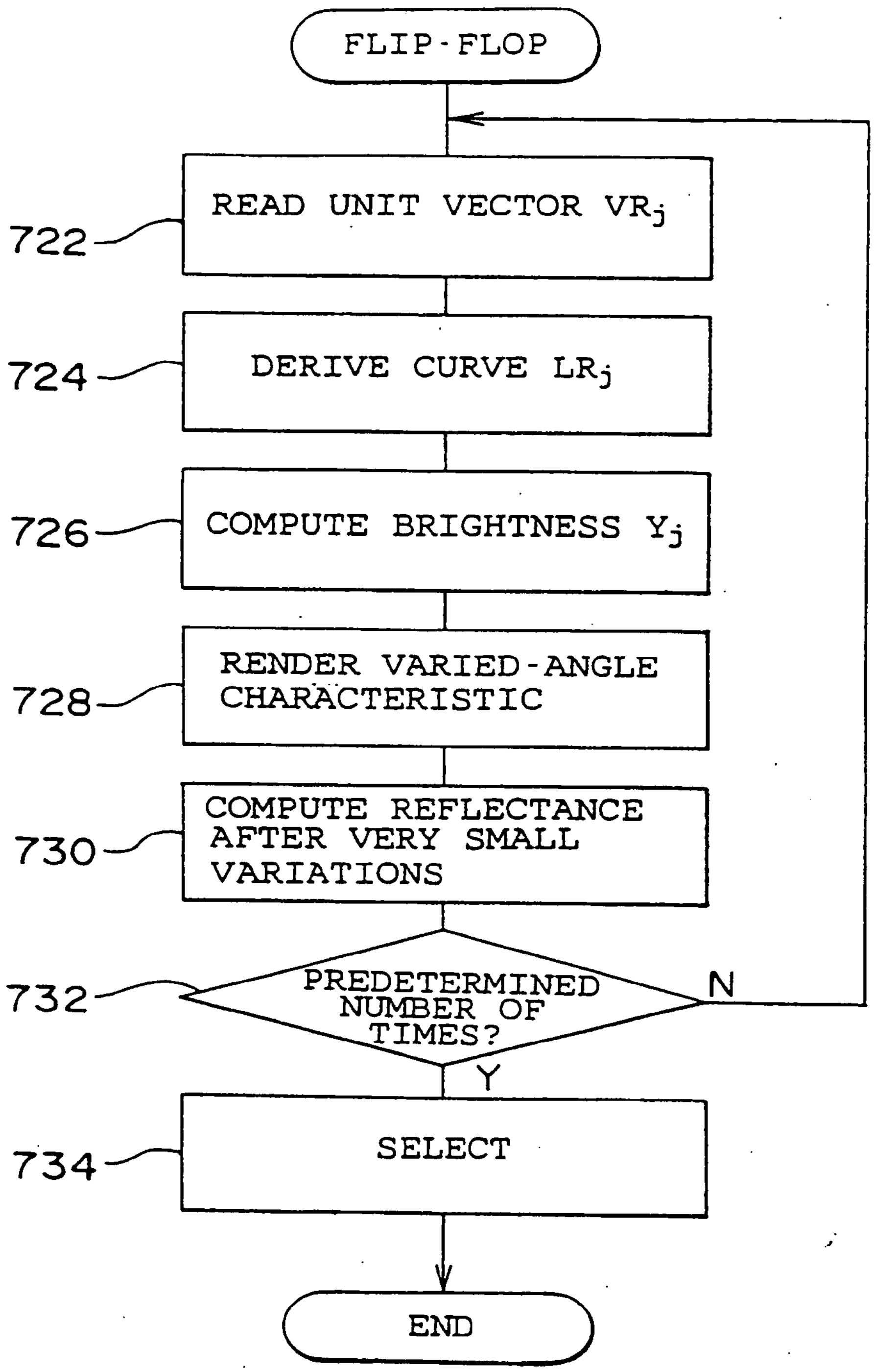

FLIP-FLOP
722
READ UNIT VECTOR VR_j
724
DERIVE CURVE LR_j
726
COMPUTE BRIGHTNESS Y_j
728
RENDER VARIED-ANGLE CHARACTERISTIC
730
COMPUTE REFLECTANCE AFTER VERY SMALL VARIATIONS
732
PREDETERMINED NUMBER OF TIMES?
N
Y
734
SELECT
END

FIG. 36

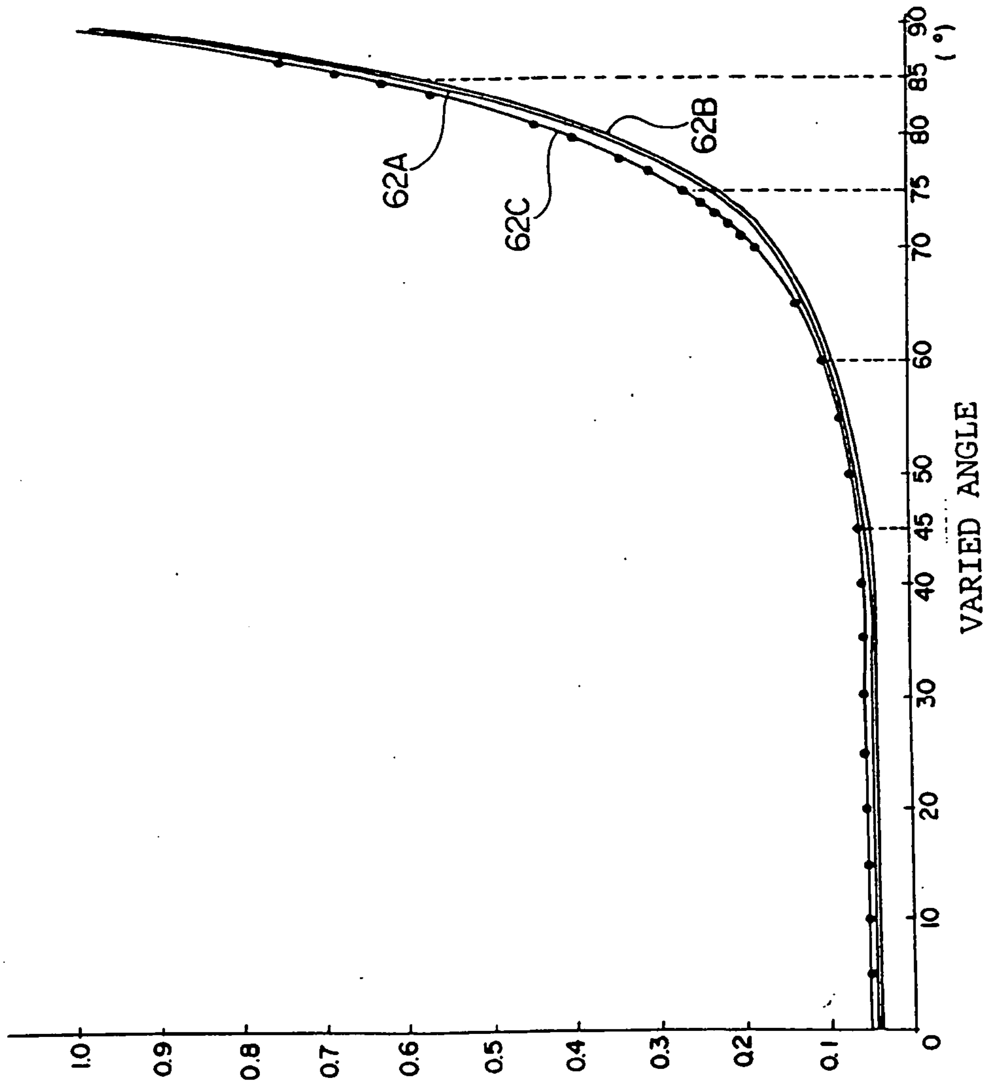

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
45
50
60
70
75
80
85
90
(°)
VARIED ANGLE
62A
62B
62C

FIG. 37A

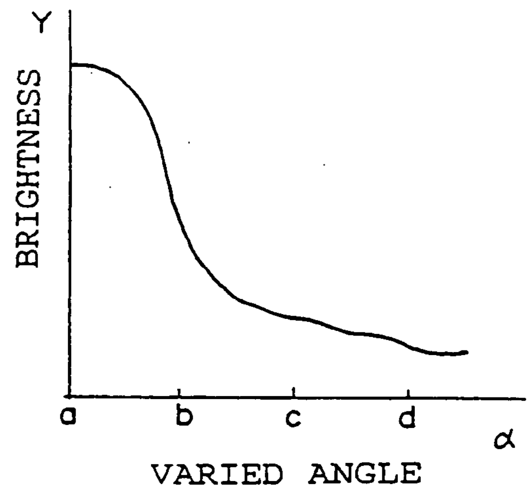


FIG. 37B

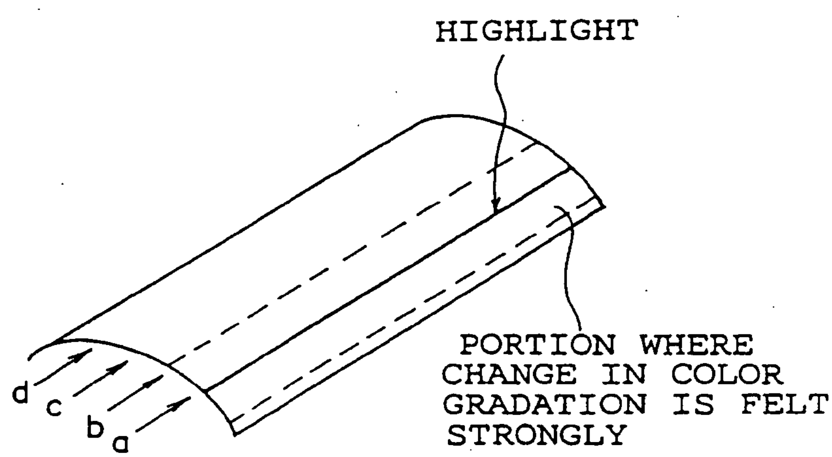


FIG. 38

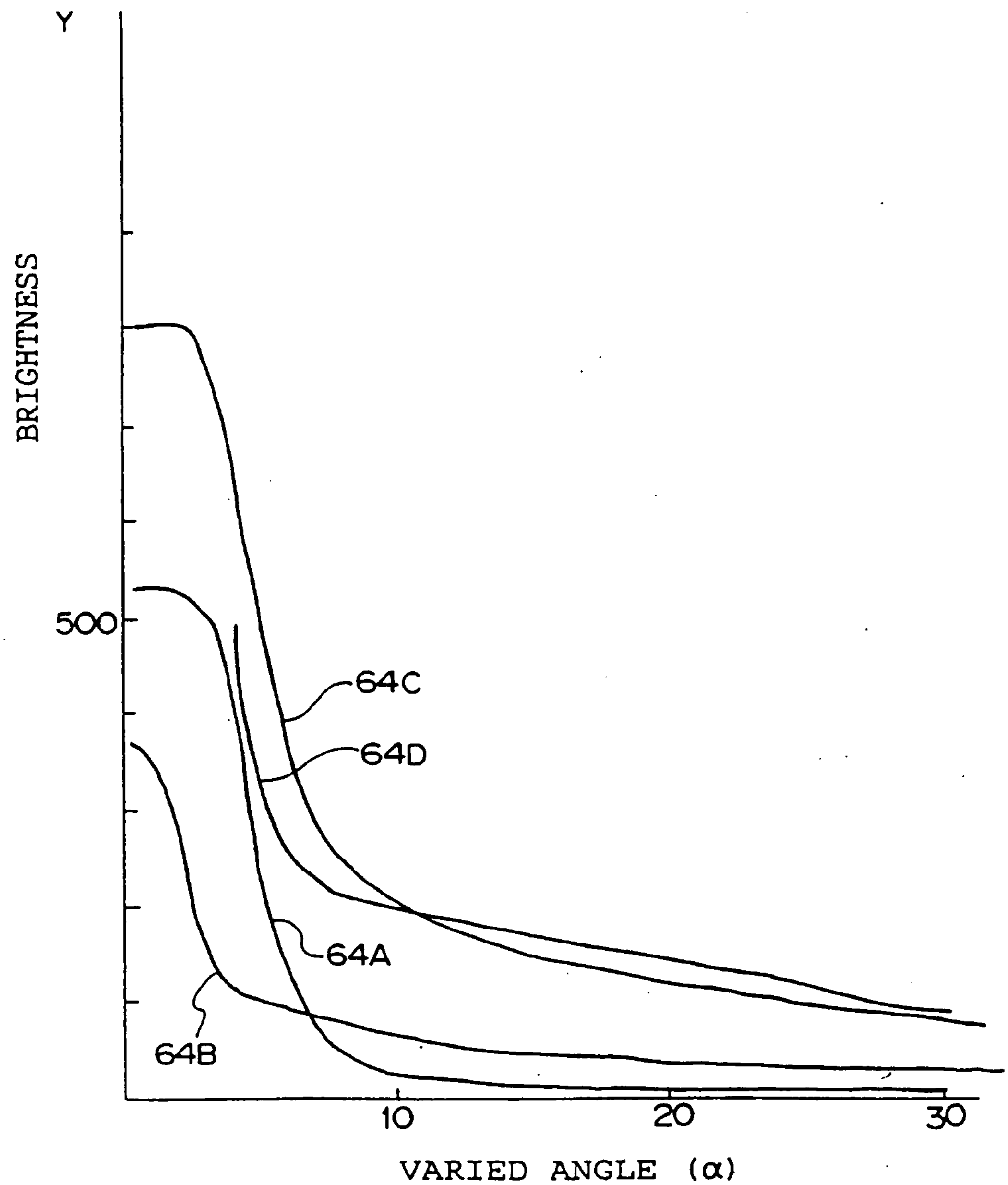


FIG. 39B

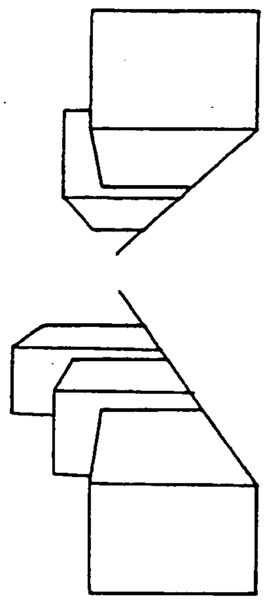


FIG. 39A

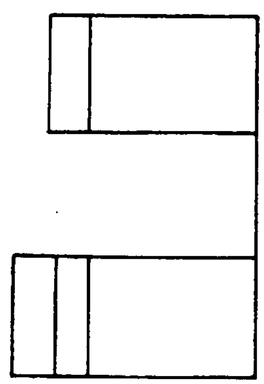


FIG. 40A

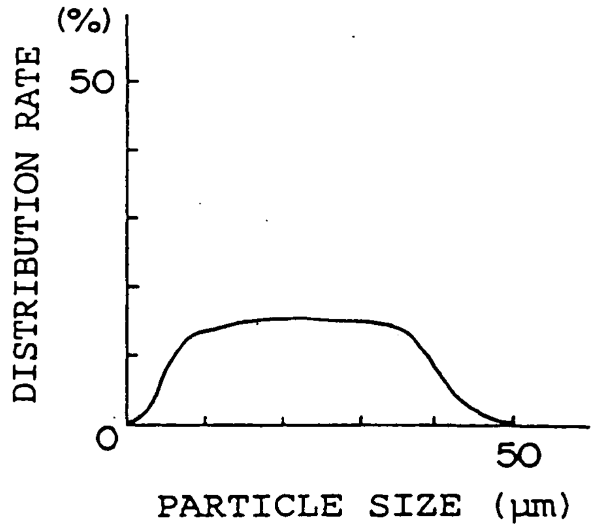


FIG. 40B

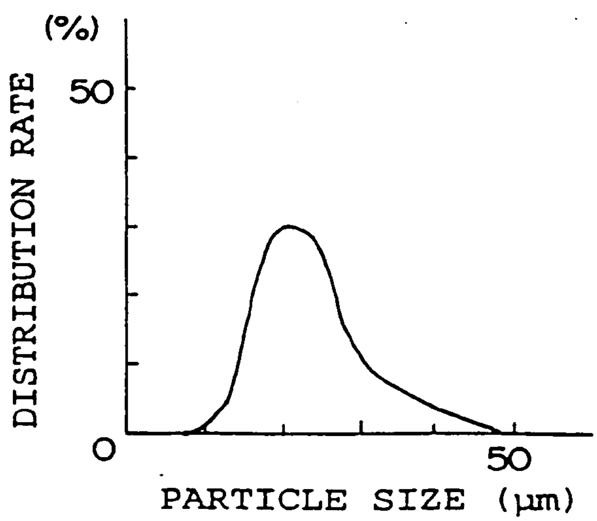


FIG. 41

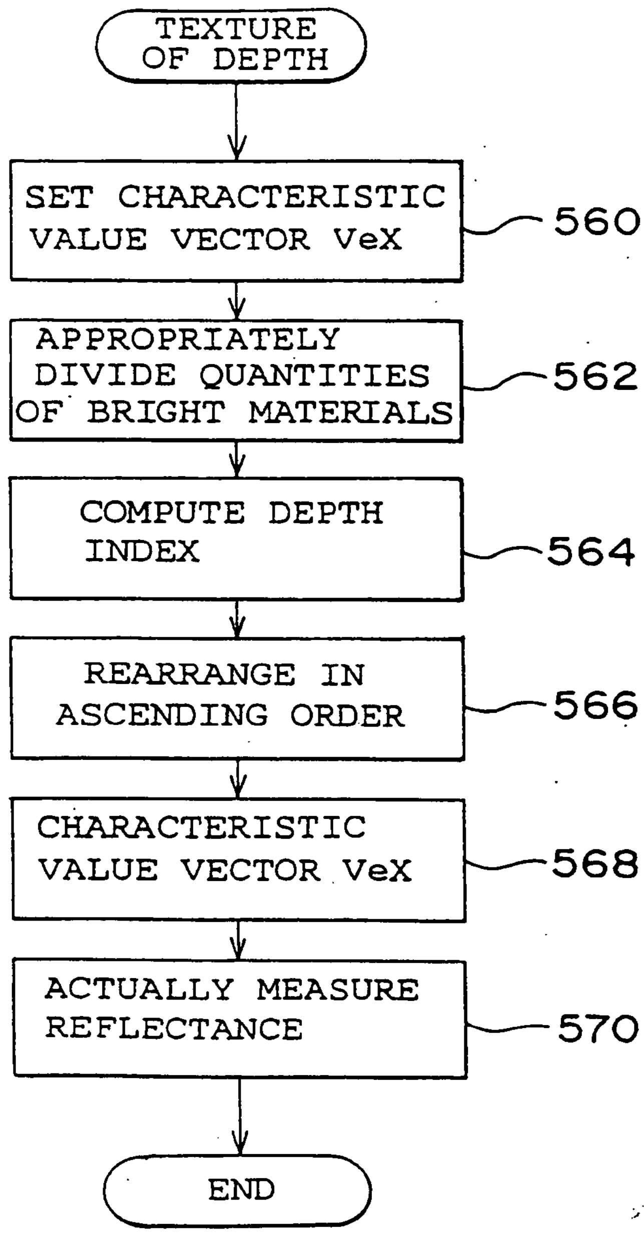

TEXTURE OF DEPTH
SET CHARACTERISTIC VALUE VECTOR VeX
560
APPROPRIATELY DIVIDE QUANTITIES OF BRIGHT MATERIALS
562
COMPUTE DEPTH INDEX
564
REARRANGE IN ASCENDING ORDER
566
CHARACTERISTIC VALUE VECTOR VeX
568
ACTUALLY MEASURE REFLECTANCE
570
END

FIG. 42

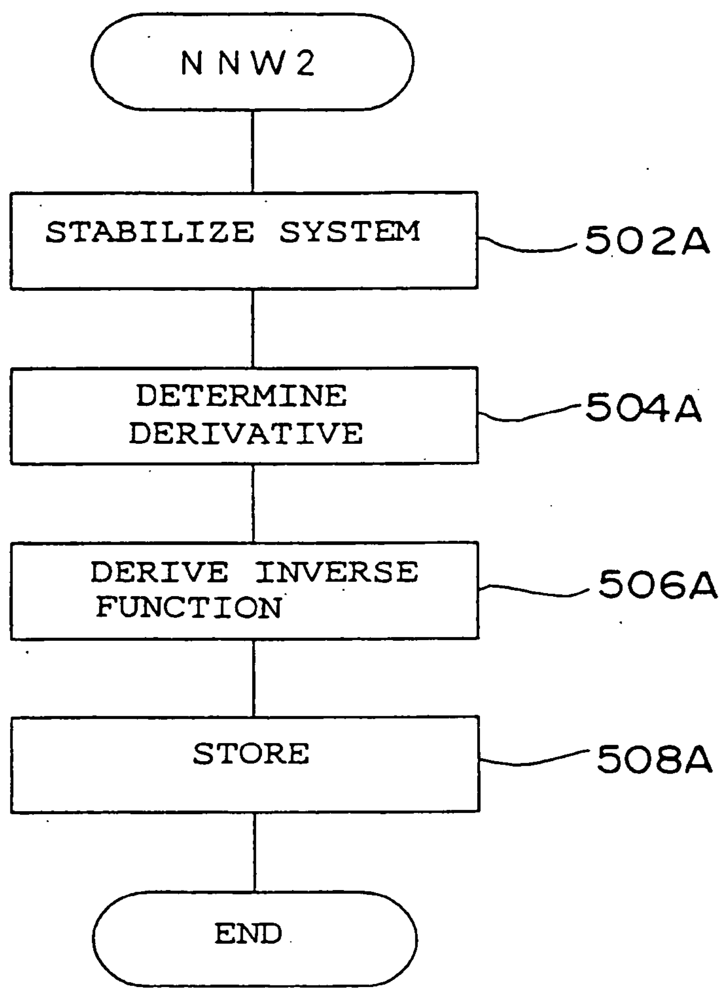
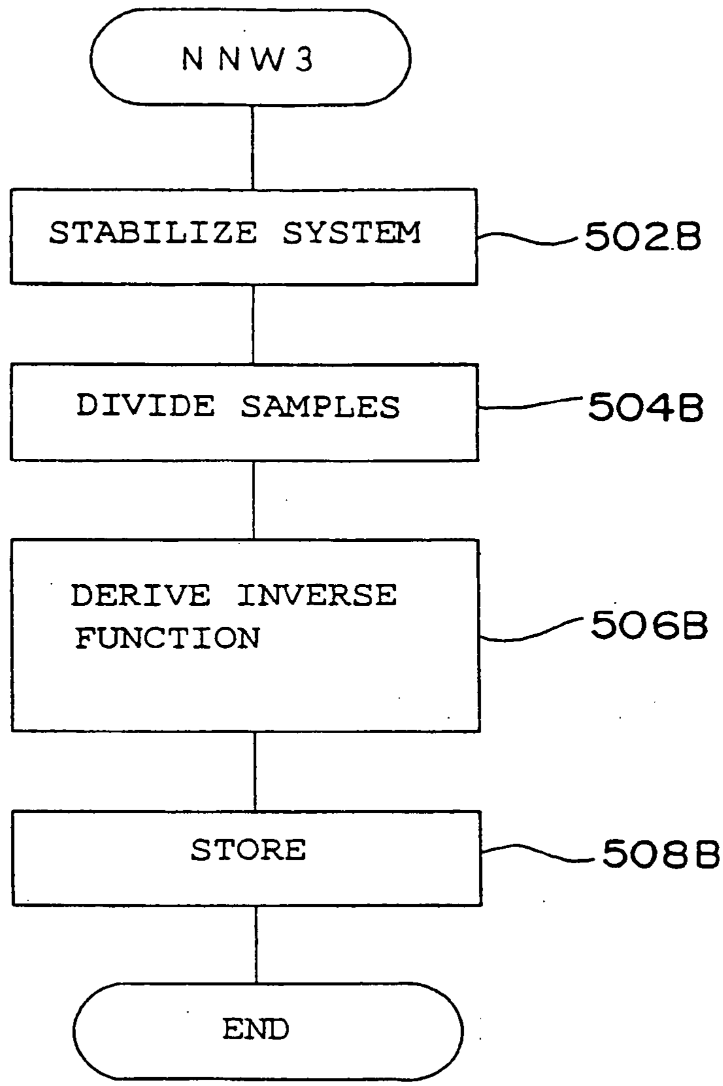

NNW2
STABILIZE SYSTEM
502A
DETERMINE DERIVATIVE
504A
DERIVE INVERSE FUNCTION
506A
STORE
508A
END

FIG. 43


NNW3
STABILIZE SYSTEM
502B
DIVIDE SAMPLES
504B
DERIVE INVERSE FUNCTION
506B
STORE
508B
END

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 97117603.7

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 6)
A	US 5033857 A (KUBOTA et al.) 23 July 1991 (23.07.91), column 2, lines 26-48, column 3, line 14 - column 9, line 59, fig. 1-8. --	1-5	G 01 J 3/46 H 04 N 1/46 C 09 D 7/14
A	WO 91/20047 A1 (EASTMAN KODAK) 26 December 1991 (26.12.91), pages 1-22, fig. 1-13. --	1	
A	US 4477833 A (CLARK et al.) 16 October 1984 (16.10.84), column 2, line 49 - column 12, line 30, fig. 1-6. --	1	
A	OSHIMA, T. et al. A CAD System for Color Design of a Car. Eurographics '92, 1992, Vol. 11, No. 3, pages C381-C390,C483, especially pages C383-C390. --	1-5	TECHNICAL FIELDS SEARCHED (Int. Cl. 6) C 09 B G 01 J G 03 F G 06 F H 04 N
A,D	TAGAKI, A. et al. Accurate Rendering Technique Based on Colorimetric Conception. Computer Graphics 1990, Vol. 24, No. 4, pages 263--272, chapter 3. ----	1-5	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	19-11-1997	BAUER

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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& : member of the same patent family, corresponding document

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